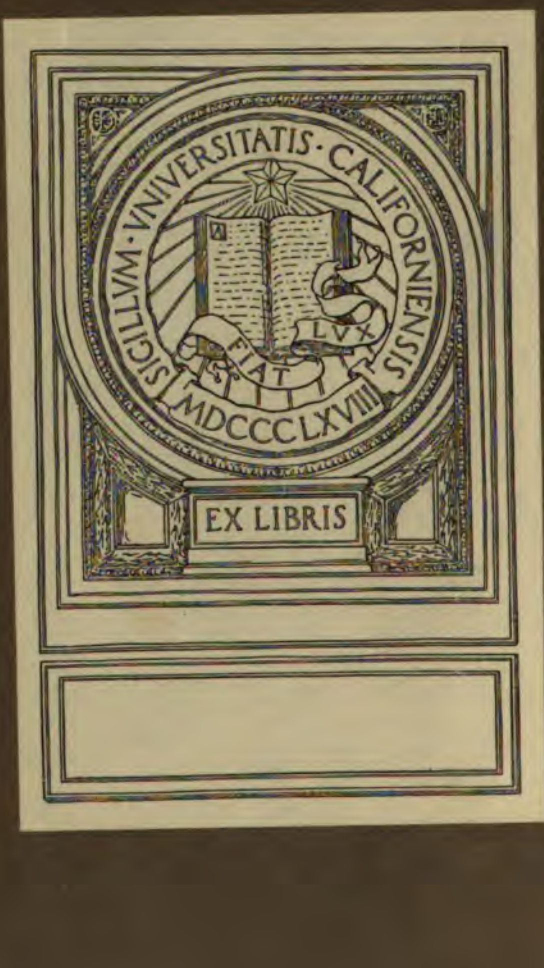
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NAVAL CONSTRUCTION

NAVAL CONSTRUCTION

PREPARED FOR THE USE OF THE

MIDSHIPMEN

OF THE

UNITED STATES NAVAL ACADEMY

BY

R. H. M. ROBINSON

Member of Council Society of Naval Architects and Marine Engineers

Late Naval Constructor, U. S. N.

THIRD EDITION

ANNAPOLIS, MD.

THE UNITED STATES NAVAL INSTITUTE

1914

The Lord Baltimore Press
BALTIMORE, MD., U. S. A.

PREFACE

This book has been prepared at the request of the head of the Department of Marine Engineering and Naval Construction at the U. S. Naval Academy, to provide a modern text-book in the course of Naval Architecture for Midshipmen of the first class. It has been prepared with a view to the special requirements of that Institution, and as it presupposes the preliminary training in mensuration and mathematics that a Midshipman of the first class must have, a considerable portion of the matter usually found in elementary works on this subject has been omitted from the part devoted to calculations.

The part devoted to practical construction has been prepared with a view to furnishing only such information as would be desirable to a line officer, and is in no sense intended as a complete treatise.

Should the student desire to pursue any of the subjects further, a number of references are given at the end of each chapter to works and articles treating of the subject of the chapter.

In the chapter on *Building, Launching,* and *Docking,* no attempt has been made to give other than general knowledge of the methods employed.

The entire book, being intended for officers of the U. S. Navy, has been based upon the practice of that service.

Several subjects within the province of the naval constructor in the U. S. Naval Service have been omitted in order to prevent duplicating the Midshipmen's course of study, as the author is informed that these subjects are treated in other branches of the Department of Marine Engineering and Naval Construction.

The Department having approved the use of such official drawings as were applicable, I am indebted to Rear-Admiral W. L. Capps, U. S. N., Chief Constructor of the Navy, for access to the files of the Bureau of Construction and Repair, to Naval Con-

structor J. H. Linnard, U. S. N., for assistance on the Stability Chapter, and to Messrs. L. Prior, W. M. Wallace, P. B. Brill, and H. W. Thayer, of the Bureau's drafting force, for their assistance in selecting and putting in suitable form the illustrations.

R. H. M. ROBINSON,
Washington, D. C.

June, 1906.

PREFACE TO EDITION OF 1909

This revision has been undertaken at the request of the Department of Marine Engineering and Naval Construction. It consists principally in putting certain articles in the theoretical part into such form as to be more readily understood by the student, and enlarging the chapters on Oscillations and Resistance.

The chapter on Oscillations of Ships is taken from a pamphlet on this subject compiled by Lieutenant-Commander R. C. Moody, U. S. N., to whom the credit therefor is due.

The chapter on Resistance and Model Tank is reprinted in part from an article by the author in the Proceedings of the Naval Institute, and for the greater part of the description of the U. S. Model Basin and its apparatus the author is indebted to the Society of Naval Architects and Marine Engineers, and to Naval Constructor D. W. Taylor, U. S. N., with whose permission they were used.

Appendices I and II comprise generally such definitions of the terms ordinarily used in Naval Architecture and Shipbuilding as are not directly defined in the text of the book.

Certain alterations and additions have also been made to conform to the latest practice in ship construction.

No attempt has been made to treat of the subject of ship design, as being beyond the scope of the Naval Academy course.

PREFACE TO EDITION OF 1914

This further revision has been undertaken to make the book more fully conform to the needs of the Academy curriculum, as to arrangement, and to bring up to date the constantly developing features of a strictly naval nature.

In writing the original book and in undertaking the two revisions the author has had considerable difficulty in restricting the subject matter to the space permissible in a book of this character.

The subjects treated of cover so much ground that in treating them thus in outline much must be omitted.

The section of the New York and of the modern destroyer included in this book are used with the permission of the Secretary of the Navy, and while not the latest ships are the latest which the Navy Department thought it wise to publish.

TABLE OF CONTENTS.

CHAPTER NO.	TITLE.	PAGES.
I.	Historical	1 to 5
II.	Definitions	6 to 14
III.	Planning a Ship	15 to 21
IV.	Calculations	22 to 44
V.	Conditions of Equilibrium	45 to 72
VI.	Stability	73 to 93
VII.	Steering and Turning of Ships	94 to 100
VIII.	Oscillations	101 to 148
IX.	Strength	149 to 153
X.	Resistance, Model Tank and Tank Experiments	154 to 167
XI.	Building Ways, Launching, etc	168 to 185
XII.	Materials, Tests and Fastenings	186 to 213
XIII.	Keels and Framing	214 to 238
XIV.	Decks, etc	239 to 253
XV.	Outside and Inner Bottoms, etc	254 to 266
XVI.	Watertight Subdivision, etc	267 to 286
XVII.	Stems, etc	287 to 298
XVIII.	Armor, etc	299 to 333
XIX.	Auxiliaries	334 to 340
XX.	Coaling, etc	341 to 349
XXI.	Ventilation	350 to 363
XXII.	Corrosion	364 to 373

Plans Having General Application to the Text:

Plate I. Sheer draft.
II. Displacement curve.
III. Midship section.
IV. Inboard profile.
V. Main deck and second deck plans.

CHAPTER I.

HISTORICAL.

Up to well into the nineteenth century, wood was practically the only material used for shipbuilding and sails the only means of propulsion. Owing to the increase in the size of ships, made possible by the introduction of steam as a motive power, wood became unsuitable because of the stresses to which the longer and larger ships are subjected. Wood had the advantage of ease of manipulation and ease with which excessive fouling was prevented, as copper could be attached directly to the hull. The local strength and stiffness of the structure of a wooden ship was great, but the strength of the structure as a whole was less than is possible with metal construction.

A few examples of iron shipbuilding are on record during the latter part of the eighteenth century, mostly applied to canal boats and barges. The first iron steamboat of which there is definite record was the *Aaron Manby,* built in 1820. The first iron warship in our service was the U. S. S. *Wolverine* (formerly the *Michigan*), still in commission on the Great Lakes.

As the size of merchant and passenger steamers increased more rapidly than the size of warships, the introduction of metal into shipbuilding for merchant purpose was, consequently, quicker than in the naval service. In our service, experience in the Civil War with the construction of the *Monitor* and other vessels of this type, served to furnish an impetus for iron shipbuilding for naval purposes, and while up to 1880 a number of wooden ships were still built, iron was in the preponderance for such new construction as was undertaken.

Our present modern Navy dates from the early 80's, the use of steel as a material for construction of hulls being first adopted for the *Dolphin, Boston, Atlanta,* and *Chicago,* laid down in 1883. The transition from iron to steel, beginning not long before these

vessels were laid down, permitted of somewhat lighter scantling than iron, and consequent decrease of the dead weight of hull and corresponding increase in the power to carry weight for propulsive and for offensive and defensive purposes. The improvement in the methods of manufacture of steel since that date has permitted many improvements in the systems of framing and attachment. It was early found that iron and steel vessels required unusual care in the preservation of the hull, iron and steel immersed in sea water being subject to rapid corrosion. The British service has built a number of steel vessels sheathed with wood so that they may be coppered. We have in our service several composite gunboats, *i. e.,* steel frames with wood planking instead of plating, but only one class (*Denver* class) of six ships sheathed and coppered. The British and other foreign navies, except in isolated cases for foreign service, seem to have abandoned the practice of building sheathed ships, which are more expensive in first cost, and less speedy.

With an unsheathed ship, up to the present time, the only method of preventing the fouling by marine growth is by docking and painting at reasonable intervals. This will be treated of in a later chapter of this book.

The methods of propulsion for naval vessels have changed rapidly.

The first departure from sails as a sole power consisted in fitting auxiliary steam machinery to be used in conjunction with sails or as a motive power in entering or leaving port or where the wind did not serve.

Our early steam frigates had full sail power also.

The development of the steam engine from simple to compound and then to triple expansion resulted in the gradual disappearance of sail power.

Scotch boilers succeeded box boilers and in turn gave place to water tube boilers.

Turbines made their appearance as practical propelling machines in the closing years of the nineteenth century.

Twin screws succeeded single screws, giving added flexibility of maneuvering and greater certainty of action.

Oil fuel in many instances is supplementing or supplanting coal for use under boilers and recently the internal combustion engine of the Diesel cycle looms up as a motive power for vessels using the oil fuel direct in the cylinder.

Speeds of battleships have increased from 15 knots to 21 knots in 20 years.

Cruiser speeds have increased from 20 to 30 knots and torpedo craft from 20 to 32 in the same time.

The submarine is a practicable weapon and the aeroplane and dirigible are being rapidly developed for naval purposes.

The change in the types of ships has also been very marked. In the old days of the wooden sailing line-of-battle ship, the battery was so arranged that the fire was nearly all broadside. The present day battleship embodies some of the essential features of Ericsson's *Monitor* in the form of center-line turrets which permit of end-on as well as broadside fire.

The character, caliber and method of mounting guns on board ship have kept pace with the development in other lines. The first step in advance was the substitution of rifled for smooth-bore guns, then breech-loading for muzzle-loading. From this point the development was rapid, both in range, muzzle velocity and caliber. Modern battleships carry 14-inch guns and greater calibers are in contemplation. Our earlier battleships carried several calibers of guns, usually 12-inch, 8-inch, 5-inch and smaller guns.

With minor changes this principle was adhered to until the design of the *Michigan* class, when the dreadnought type (so-called after the British vessel of that name) was begun, carrying only one caliber of main battery guns, supplemented by one caliber of torpedo defense guns.

The mounting of main battery guns has developed along progressive and rational lines. Our early battleships had a heavy turret in center line forward and aft and the second caliber disposed in smaller turrets on the quadrilateral plan. The *Kearsarge* class and *Virginia* class placed the second caliber guns on top of the main battery guns in the so-called superposed turrets. The *Michigan* class

introduced the vertical echelon arrangement of main battery turrets, the second firing over the first. This system, first introduced in our service, is now the accepted method of mounting such guns the world over.

Recently the three gun turret is supplanting the two gun turret, considerations of fire control and economy of displacement outweighing the possibility of increased loss of offensive power in case of injury to a turret.

The secondary or torpedo defense battery, in the United States service, is generally mounted in redoubts or casemates arranged essentially for broadside fire; but in some foreign services nearly the entire installation is made in turrets.

In our service the freeboard has undergone many changes. The old frigates and line-of-battle ships were high-sided, from which type we jumped to the monitor, and have, in our heavy fighting ships, gradually worked back until we again have high-sided ships. The elevated gun positions give advantages in permitting the use of guns in a seaway, the high freeboard gives greater range of stability, and the whole structure is a better gun platform than the low-freeboard ships; it, however, offers a greater target.

The introduction of shell fire made it necessary to provide means for excluding the missiles, which led to the adoption of armor, at first made of laminated plates, later of wrought iron, then of compound, then of nickel steel, then Harveyized, and now the Krupp and other similar processes.

The first British ironclad ship was an iron ship—the *Warrior*. In our service, the *Monitor* was of iron, but the Confederate ram, *Virginia,* was the old wooden U. S. frigate *Merrimac*, razed and plated with railroad iron and boiler plates.

There has likewise been a marked increase in the size of vessels of the United States Service since the beginning of the modern Navy. The following tabular comparison of the principal characteristics of first-class ships of various parts of this period, beginning with the *Boston*, down to the present day, selecting types of each date, is given for the information of the students, as

indicating the increase in size, armament and cost of first-rate men-of-war in the U. S. Service:

Name.	Type.	Building date.	Length.		Breadth.		Draft.		Displacement.	Armament.	Speed.	Contract price.
			ft.	*in.*	*ft.*	*in.*	*ft.*	*in.*			*knots.*	
Chicago.. (Original)	Protected Cruiser	1883–87	315	0	48	2	19	0	4,500	4 8″ 8 6″ 2 5″	15.8	$889,000
Columbia	Protected Cruiser	1890–94	411	7	58	2	22	6	7,350	1 8″ 2 6″ 8 4″ 19 small	22.8	2,725,000
Brooklyn	Armored Cruiser	1893–96	400	6	64	8	24	0	9,215	8 8″ 12 5″ 23 small	21.9	2,986,000
Indiana..	Battleship	1890–95	348	0	69	3	24	0	10,288	4 13″ 8 8″ 4 6″ 29 small	15.5	3,063,600
Maine....	Battleship	1899–02	388	0	72	2	23	10	12,500	4 12″ 16 6″ 24 small	18.0	2,885,000
Connecticut	Battleship	1902–06	450	0	76	10	24	6	16,000	4 12″ 8 8″ 12 7″ 50 small	18.0	4,212,000
Florida..	Battleship	1908–11	510	0	88	2	28	6	21,825	10 12″ 16 5″ 6 small	20.75	3,947,000
Pennsylvania	Battleship	1913–	600	0	97	0½	28	6	31,400	12 14″ 22 5″	21.0	*7,425,000

*Limit of cost

REFERENCES FOR MORE COMPLETE STUDY IF DESIRED:

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CHAPTER II.

DEFINITIONS.

Pertaining to the Lines of a Ship.

The Sheer Draft (see Plate I) is a line drawing of a ship's form including the following:

The sheer plan, a longitudinal elevation or side view of the ship; it is usually arranged with the bow towards the right and the stern towards the left; on it are shown the boundary lines of the ship, viz., the keel, contour of the stem and stern, the rail and different deck lines at the side, the waterlines, the bow and buttock lines, and the diagonal lines and cross section stations.

The half-breadth plan, representing the horizontal plan of one side of the ship, which is sufficient, as both sides are symmetrical; in it appear the forms of the various waterlines, rail and deck lines at the side, the cross section stations, and the bow and buttock lines and development of diagonals.

The body plan, consisting of a pair of half transverse elevations or end views of the ship, both having the same vertical middle line, so that the right-hand side represents the ship as seen from ahead, and the left-hand side as seen from astern. Both sides of the ship being symmetrical, it is required only to draw one side. On the body plan appear the forms of the various cross sections, the curvature of the rail and deck lines at the side, the waterlines, bow and buttock lines, and the diagonal lines.

In two of the plans, viz., the sheer plan and body plan, the waterlines appear as straight horizontal lines, while in the half-breadth plan their curvature or form is shown. Their endings in the half-breadth plan are obtained from their intersection with the stem, stern post, and stern in the sheer plan.

In large vessels, the waterlines are generally spaced two feet apart, commencing from, and running parallel with, the load waterline, while in small vessels the distance between them is reduced. Waterlines are generally designated in the different plans by their

distance from the base line, viz., 4 feet, 8 feet, or 12 feet waterline, etc., commencing with the one nearest to the keel.

The cross sections appear as straight vertical lines in the sheerplan and half-breadth plan; in the former they stand perpendicular to the waterlines, and in the latter, perpendicular to the center line. In these two plans, the distance apart of frames, measured from molding edge to molding edge, called the frame space, is sometimes shown.

In the body plan the contour or form of the cross sections is shown, but not their distance apart. The largest of the cross sections, or rather the widest at the load waterline, situated generally at or near the middle of length of the ship, is called the *midship section* or *dead flat,* and is marked with the symbol ⊗ on the plans. While in the body plan all the other cross sections appear only on one side of the vertical center line, the forward ones on the right and the after ones on the left, the midship section ⊗ is shown on both sides.

The midship section divides the ship into two parts, called respectively the *fore-body* and the *after-body*. Sometimes there is a part of the ship, at or near the middle, which has a uniform cross-section throughout its length, its waterlines being parallel to the center line; this, when it exists, is called the *middle-body,* or sometimes the *parallel middle-body.*

To enable the same cross section stations to be readily found on the different plans, they are marked with numbers in their order from bow to stern.

The three plans are closely connected inasmuch as all the principal lines are shown in each of them. The ordinates of either one are repeated on, or transferred to, at least one of the other plans, which is also the case with the intersections of any two sets of lines. Thus, all the ordinates of any waterline, taken from the half-breadth plan, are found on the corresponding waterline of the body plan; and all the waterline ordinates which define the form of a frame or cross-section are found on the corresponding frame or cross-section in the half-breadth plan.

All intersections of bow and buttock lines with the waterlines and rail or deck lines in the half-breadth plan, and with the cross-

sections or frames in the body plan, are transferred to their corresponding waterlines and cross-sections or frames in the sheer plan, thus giving the points which define the curve of the bow and buttock lines in that plan.

The sheer plan shows position of all ordinates, but not their length. The half-breadth plan shows their lengths and positions lengthwise, but not vertically. The body plan shows their lengths and positions vertically, but not lengthwise.

The lengths of ordinates and their positions being shown in any two plans, sufficient data are given to show the figure of the ship completely; but the three plans together give the mind a more distinct idea of that figure and are more convenient for purposes of measurement and calculation.

Any two of the plans being given, the third may be constructed therefrom.

Waterlines are lines which the surface of the water forms with the side of a vessel at various successive depths of immersion parallel to the load waterline or base line; they appear straight in the sheer plan and body plan, while their curvature or form is shown in the half-breadth plan.

Deck lines are the lines representing the form of the deck in the half-breadth plan; in the body plan and sheer plan they are represented by the curves passing through the intersection of the deck heights with the side of the ship.

Deck lines at side are the lines showing the fore and aft curvature of the deck at side in the sheer plan, and the excess of the freeboard at bow and stern over that amidships. In the body plan they are represented by the curve passing through the intersection of the deck heights with the side of the ship.

Bow and buttock lines are formed by longitudinal vertical sections or planes parallel to the longitudinal vertical central plane which divides the ship into two symmetrical halves. In connection with the waterlines, they are of great service in regulating or fairing the bow and stern, and in connection with the cross-sections or frames, are valuable to fair up the ship's bottom, as will be treated of later. In the body and half-breadth plan they appear as straight lines, while in the sheer plan their form or curvature is shown.

Diagonal lines are represented in the body plan by straight lines crossing the waterlines obliquely. They are of special use for regulating the bottom and bilge and laying down and fairing up, as they intersect the outer surface of the ship at nearly right angles. In the sheer plan they are generally shown at the extremities for the purpose of fairing in connection with the bow and buttock lines. As seen in the diagonal plan, they make the ship appear of greater width than she really is, on account of their oblique direction.

The sheer of a vessel is the longitudinal curve of the rail, decks, etc., which shows the difference of height above water, or freeboard, at the stem and stern over that amidships.

Sheer lines appear in the body and sheer plan, and are simply required to determine the upper ending or head of the frames, or to mark the height of the deck beams at side. The height of the rail or decks is taken on each cross section from the sheer plan and is transferred to the body plan. Lines parallel to the waterlines are struck in through the points so transferred, and on these plans the respective half-breadth of the rail or deck line, taken from the half-breadth plan, is set off.

Base line.—This is to the naval architect the line from which all vertical dimensions and heights are measured. In the U. S. Service, for ships designed without a "drag," it is a line coincident with the top of the keel. In foreign services it is generally coincident with the top of keel. For a ship with a "drag," it is a line parallel to the waterlines and tangent to the top of keel at the dead flat.

Forward perpendicular is a line perpendicular to the keel line and intersecting the forward side of the stem at the designed load waterline. This is known as F. P.

After perpendicular is a line perpendicular to the keel line, intersecting the after contour of the stern at the designed load waterline. This is known as A. P.

Mid perpendicular is a line perpendicular to the keel line and taken midway between the forward perpendicular and the after perpendicular. This is known as M. P.

Length between perpendiculars is the dimension used by naval architects in connection with the design of ships; it is measured

from the forward perpendicular, or F. P., to the after perpendicular, or A. P.

Length over all is the length measured from a line perpendicular to the base line and tangent to the most forward projection of the

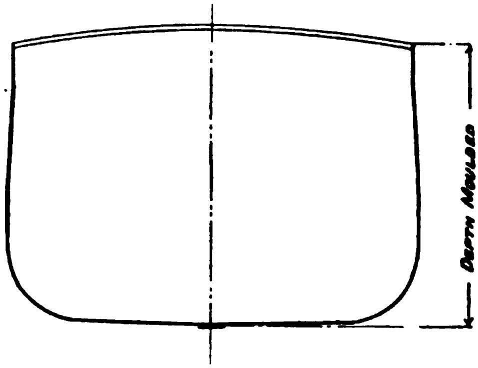

FIG. 1.

stem, to a line perpendicular to the base line and tangent to the after end of the stern.

Moulded breadth is the width of the widest frame at its outside and is therefore a dimension taken inside of all shell plating.

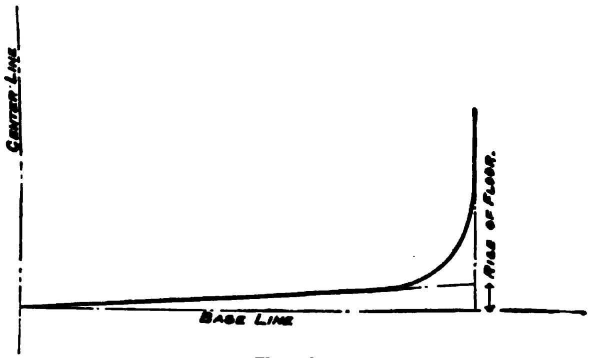

FIG. 2.

Breadth extreme is width over outside of shell plating or armor plating at widest frame.

Depth moulded is the depth from the top of the keel to the top of the main deck beam at side.

Rise of floor is the amount a tangent to the outside of the midship frame, starting at the intersection of center line with base line, rises above the horizontal in the half breadth of the ship.

Camber or round up is the curvature, convex toward top, given to deck beams to add to the arch strength of the structure and insure proper drainage of decks.

Designer's waterline is a more or less arbitrary waterline at which the ship is designed to float in a particular condition of loading. In the U. S. Service this condition of loading is ship and all appurtenances complete, crew complete, full ammunition and two-thirds the full amount of all other consumables, *i. e.*, stores, fuel, etc., this being assumed as the most probable average condition of loading when going into battle.

Draft is the depth from waterline to bottom of keel when a vessel is afloat.

Draft aft is that measured at the stern.

Draft forward is that measured at the bow.

Mean draft is the average between that measured at bow and at stern, or that measured at middle of length.

Light draft is that at light displacement.

Load draft is that at load displacement.

Draft extreme is that measured to the lowest projecting portion of the vessel.

Trim is the difference in draft at bow of a vessel from that at the stern.

Drag is the designed excess in draft aft over that forward. This is little used in modern warships, though often found in yachts and other sailing craft.

The following extract from the instructions governing the location of draft marks in the U. S. Service is quoted:

"1. Draft marks shall be in Arabic numerals, except as specified below, and for numbers greater than 10 the last figure only of the number shall be used. Draft marks shall be cast or cut out of sheet metal and shall be secured by screws. Steel numerals and steel screws shall be used on unsheathed vessels. Where they come upon metal parts, and for metal vessels, the positions of the draft marks

shall be accurately located by punch marks or light scores. For torpedo vessels and other vessels of special light construction, metal draft figures shall not be fitted but the figures shall be outlined by center punch and painted.

"2. In every case there shall be one set of draft marks as far forward as practicable, and a second set as far aft as practicable, each consisting of a line of marks on each side. Each line of marks shall be as nearly as possible perpendicular to the designer's waterline, but minor variations, in order to follow contours of stem and stern, may be made when desirable, especially at some distance above or below the waterline.

"3. The forward and after draft marks shall be located, on vessels of ordinary form, from a base line parallel to the designer's waterline and coinciding with the bottom of the straight keel; in case of vessels with a drag, from a base line parallel to the designer's waterline intersecting the bottom of keel at midperpendicular, and for vessels with rocker keels, from a base line parallel to the designer's waterline and tangent to the bottom of keel at its lowest point.

"4. Additional sets of draft marks shall be placed abreast the lowest projection of the keel, skeg, rudder, or tips of propeller blades if they project below the base line fixed in accordance with the foregoing, such draft marks reading from this lowest projection.

"5. In case of vessels that are so much cut up aft, that after draft marks may, under certain conditions of trim, indicate a draft of water materially greater than actual maximum draft, the matter shall be referred to the bureau for instructions.

"6. For vessels requiring only the two sets of draft marks, all draft marks shall be in Arabic numerals, 6 inches in projected height, the even foot indicated being the bottom of the mark. For vessels requiring the additional set of draft marks, the marks on the bow and the marks showing the maximum draft shall be in Arabic numerals, 6 inches in projected height; the marks on the stern shall be Roman numerals, 3 inches in projected height, a horizontal mark being placed between them with its lower edge at the 6-inch interval."

Displacement.—The amount of water displaced by any floating body is called its *displacement*. In the case of ships it is generally expressed in tons; one ton of sea water being equal to 35 cubic feet, and one ton of fresh water to 36 cubic feet.

The displacement of any floating body is equal to the weight of that body, and consequently the displacement of a ship in any condition is equal to the weight of the ship with everything then on board.

Center of buoyancy is the geometric center of gravity of the immersed volume of the displacement.

Center of gravity is the resultant point at which the weight of all the individual items of the ship's weights may be considered to be concentrated.

Center of flotation is the center of gravity of the load water-plane of a ship.

Metacenter.—If a ship be inclined to a small angle and a perpendicular be drawn to the load water-plane in the inclined position

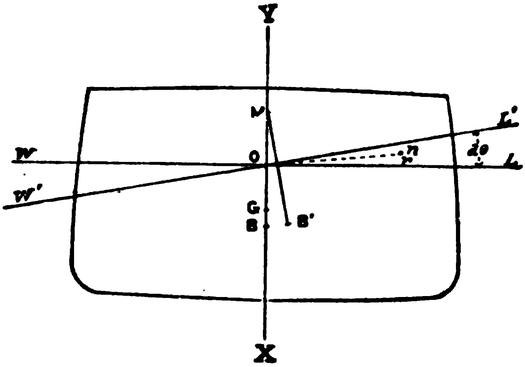

FIG. 3.

through the center of buoyancy in the inclined position, this perpendicular will intersect in some point a similar perpendicular drawn through the center of buoyancy in the upright position to the load water-plane in this upright position. This point of intersection M is the *metacenter*.

Block coefficient is the ratio which the immersed volume bears to the circumscribing rectangular solid, *i. e.*, is equal to

$$\frac{\text{displacement (in tons)} \times 35}{l \times b \times d}$$

Where $l =$ length between perpendiculars, $b =$ extreme beam, $d =$ mean draft.

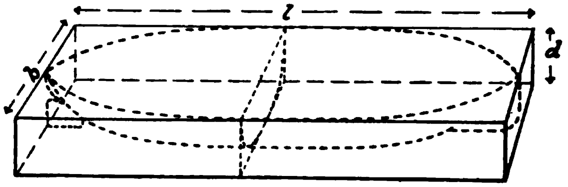

FIG. 4.

Prismatic coefficient is the ratio which the immersed volume bears to the volume of a cylinder whose length is equal to the length (B. P.) and whose base is in area equal to the area of the midship section

$$\frac{\text{displacement (in tons)} \times 35}{\text{Area } \boxtimes \times L}$$

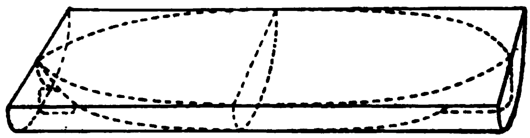

FIG. 5.

Coefficient of fineness of midship section is the ratio which the actual area of midship section below load waterline bears to the rectangle whose breadth equals breadth of this midship section and whose height equals draft, *i. e.*, the circumscribing rectangle

$$= \frac{\text{Area midship section}}{b \times d}$$

Coefficient of fineness of water-plane is the ratio which the area of any water-plane bears to its circumscribing rectangle.

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CHAPTER III.

PLANNING A SHIP.

The following brief description of the method used in the U. S. Navy for planning a ship will show to the midshipman the origin of the design and the processes by which naval vessels are produced. With minor and unessential differences a similar method obtains in all first-class foreign services.

The *first* step is the determination of service requirements, which means deciding what types of ships and how many are needed to enable the fleet to perform the functions expected of it. In the U. S. Service this determination is made by the General Board, a board of naval officers of rank and experience who consider the questions of strategy and tactics and international politics involved and after due deliberation report to the Secretary of the Navy that the fleet needs certain numbers of various types of ships. The report of this board covers what are termed the military characteristics of the types, *i. e.*, speed, radius of action, general statements as to character of offensive powers and degree of defensive power, leaving the details for development.

Since the building of war vessels, particularly the larger types, requires large amounts of money and may affect international politics largely, the recommendations of the General Board of the Navy are frequently modified by the Secretary of the Navy and are often the subject of discussion in the Cabinet of the President. This consideration is usually more as to numbers than as to the details of the types. Recommendation is then made to Congress, who must authorize the expenditure and appropriate the money before actual building can begin.

Having decided on the types needed for the fleet, the Bureaus of the Division of Material of the Navy Department are instructed to prepare sketch designs—the *second* step. The three bureaus concerned are Construction and Repair, Steam Engineering and

Ordnance. As a matter of practical fact the sketch design is prepared by the Bureau of Construction and Repair, whose personnel includes the naval architects of the service. The Bureaus of Steam Engineering and Ordnance furnish to the Bureau of Construction and Repair for use in this sketch design, plans, weights and other information as to guns, ammunition, propelling machinery, etc., necessary to permit the preparation of the sketch design and the estimate of dimensions, displacement and other qualities to accompany the same.

The naval architect stands in relation to the design of a ship in much the same place that the architect does to the design of a building, *i. e.,* he receives an outline statement of the purposes of the building, accumulates data as to the materials, etc., and then prepares his plans. The preparation of these preliminary sketch plans is of the utmost importance and the number of solutions possible to any set of characteristics propounded is large, so that several sketch plans are often prepared. The preparation of these plans and the data to accompany them can only be undertaken from the possession of much accumulated data and experience and takes the form of a series of approximations, supplemented by calculations, and the result may be assumed to be accurate within, say 3% to 5%, this degree of inaccuracy being eliminated in the later final calculations for the actual ship. For example, taking the characteristics presented, the naval architect first approximates roughly to the increase in displacement over the last class of the same type, noting any essential changes in speed or maneuvering required which may affect the fineness of underwater form. From this rough approximation he approximates to his new dimensions and coefficients. He then makes sketches from which he makes more accurate calculations of weight, determination of horse power from model tank data, approximate investigation of stability, etc., and probably finds it necessary to modify his first approximation to dimensions and coefficients. By a series of such approximations and calculations, varying in number according to the expertness of the individual and the accuracy of his data, he eventually arrives at a combination of dimensions which he uses in the actual sketch design.

In this process he must consider flotability, stability, mobility

(including speed and radius of action) and strength as well as the purely military questions of offense and defense. He must consider the probable effect of damage above and below the waterline, and numerous other matters. In preparing the sketch design questions of internal arrangement arise concerning the comfort, utility and habitability for the numerous men in the crew. The design of any war vessel is in the nature of a compromise between the various features of offense, defense and mobility.

In the larger type battleships there is a more or less definite limit to size imposed either by Congressional action, size of dry-docks, or depths of harbors, and frequently all the desired characteristics cannot be obtained on dimensions which are practicable.

In any design it is usually unwise to sacrifice too much to one of the three qualities mentioned above, although the different types have the three qualities in different degrees. For example, the battleship sacrifices speed to offense, defense and radius.

The battle cruiser sacrifices some defense and radius to offense and speed.

The destroyer sacrifices defense altogether to offense and speed; and so on.

Finally the sketch design, or perhaps more than one, is completed and is referred to the General Board with a table of data showing dimensions, speed, radius of action, fuel and ammunition capacity, battery, protection and other qualities. This may be called the *third* step. As a *fourth* step, the General Board approves one of the sketch designs or makes suggestions as to modifications in same, usually minor in character, when we reach the *fifth* step.

The Actual Design.—This design is based on the sketch design selected and is also performed by the three bureaus mentioned above, or, as is actually the case, the design of the ship is made by the Bureau of Construction and Repair, except the details of propelling machinery and battery, which are performed by the other bureaus, frequent consultation between the bureaus being necessary as their work is interdependent. The actual design comprises the preparation of plans and specifications and the final calculations for displacement, trim, stability and strength, the preparation of the final model and the accurate determination of its resistance so that the

machinery may be designed to develop the requisite horsepower without fear of undue excess or deficiency.

The plans made cover

(1) Lines, showing form of ship.

(2) Midship section, showing distribution of material and methods of fastening.

(3) Deck plans, showing internal arrangements and dimensions.

(4) Armor plans, showing location, thickness and fastening of armor.

(5) Turret plans.

(6) Type plans of piping, for ventilation, drainage, fresh water systems, etc.

The specifications define in detail the thickness, size and location of each piece of material, the method of fastening and every item entering into the completed ship.

To facilitate the preparations of the specifications for a particular ship, which are called the "Detail Specifications," the Bureau of Construction and Repair has published a volume of "General specifications for building ships," which covers the work applicable to all ships, defines practice in performing work and leaves for the detail specifications only the scantlings of materials and items applicable to the particular ship.

Detailed Calculation of Weights and Centers of Gravity.—It is necessary in designing to estimate the weight and the position of centers of gravity of each part of the ship's structure, fittings, machinery and appurtenances located therein, in order that the draft, trim, and stability conditions required and decided on in advance may prevail in the finished design.

The ordinary rules of mensuration employed in ship calculations will be discussed in Chapter IV. The details of construction of the ship's structure and scantlings of its various component parts are defined in the specifications. All plates are specified in weight per square foot, and the various shapes of beams, frames, stiffeners, etc., in weight per lineal foot, the standard sizes being shown in the handbook of any steel mill, such as Carnegie's.

In the case of a bulkhead, a deck, the outside plating, or inner-bottom plating, the first step is to find the area of plating and length

of angle bars. To determine the former, the plates are laid off on a plane surface. If the plating is warped, it is developed on a plane surface so as to give, as nearly as possible, its true area. To this net area is added the area of seam-straps, butt-straps, laps, and liners. The weight of the plating is the weight of this total area, with a deduction for rivet holes. This per cent deduction varies somewhat with the size and spacing of the rivets, but is commonly taken as $1\frac{1}{2}$ per cent.

The use of curves is often of great assistance in determining the weight of certain parts of the structure. Take, for instance, the transverse framing of a ship. For a considerable portion of the length of the ship, this framing will be of the same character. Let the length over which this type of framing obtains be represented by a base line on which the location of each frame is spotted. The length of a convenient number of frames is measured from the body plan and their calculated weights set up to a certain scale as ordinates at their proper locations on the base line, and through the spots thus obtained a fair curve is drawn. This curve is the locus of the weights of all frames within the extent of the base line. The individual weights of deck beams may be determined in the same manner.

A close approximation to the total length of deck beams or stiffeners for a given area of deck or bulkhead may be obtained by dividing the area by the spacing of the beams or stiffeners. In obtaining all the first approximate areas and centers of gravity, the planimeter or integrator is of great value, but in the final calculation one of the rules given in Chapter IV is employed.

Allowances for the weights of such indeterminate portions of the structure as rivets (driven), paint, putty, and cement, are based on the returned weights of similar ships, or in an entirely new class of vessel must be calculated in great detail.

The weights of battery fittings, machinery, and appurtenances and ammunition, stores, etc., are based on official returned weights modified by the latest official data from the various bureaus having cognizance thereof.

By the use of these various methods, the weight of each portion of the complete ship may be calculated.

It is quite natural, however, from the complexity of the modern vessel of war, that such calculations must be made according to a fixed standard or grouping or classification to keep the work within reasonable limits of cost and also for purposes of comparison. Several methods of grouping the weights for such purposes suggest themselves. Without discussing such natural divisions, briefly, the method adopted in the Bureau of Construction and Repair is to group each deck separately. The outside plating, inner-bottom plating, bulkheads (transverse and longitudinal), machinery supports and fittings, are grouped separately. The propelling machinery, armor, ordnance, equipment, and outfits are likewise separately grouped. The Bureau of Construction and Repair uses fifty-five groups and keeps a carefully recorded return of actual weights as the ship is built, which is compared with the estimates, reduced to percentages, and otherwise used for new designs.

Printed forms for detailed weight calculations are provided, upon which are entered a description of the object, with its unit weight and number of units, together with leverages for each item, about two axes (the moulded base line of the ship being one, and the frame most nearly coincident with the mid-length the other). Such weight sheets are compiled according to groups and finally summarized, giving the total weight of each group, together with the derived position of its center of gravity.

All of the groups being recapitulated, the gross weight of the ship with everything on board ready for sea, is obtained, and at the same time the longitudinal position of the center of gravity of the ship and its height above the moulded base line.

From the displacement sheet (previously described), the functions of form to the load waterline are obtained, and knowing the position of the center of gravity, center of buoyancy, moment to alter trim of ship one inch, and the metacenter, the metacentric height and trim of ship are calculated.

The records of calculated weights are preserved in the Bureau, and upon completion of the vessel, careful checks are made between the calculated and actual weights as well as between the designed trim and metacentric heights and the results of the final inclining experiment.

The detail calculations are made on standard forms, several thousand sheets being employed for each ship. These are summarized and bound in a volume called *Detail Weight Calculations,* which are filed for reference and comparison as mentioned above.

Having prepared the plans and specifications bids are called for from the various ship builders if the vessel is to be built by contract, and each prospective bidder is furnished with the plans and specifications on which to estimate. He is required to hold these as confidential. If the vessel is to be built at a navy yard the order may at once be placed.

If bids are called for, 60 days are allowed by law in which the bidder may prepare his estimate of the price at which he is willing to construct the ship. These bids, when received, are analyzed and the award placed by the Secretary of the Navy, after which the successful bidder, who now becomes the contractor, is instructed to proceed with the work in accordance with the plans and specifications furnished him.

The only exception to the above practice is in the case of submarines, which, being covered by patents, are designed by the builders, following a set of general requirements issued by the Navy Department, called a Circular Defining the Chief Characteristics.

CHAPTER IV.

CALCULATIONS.

In addition to the usual drawing instruments, *i. e.*, the compass, divider, bow-pen, beam compass, T-square, triangle, and scales, the instruments usually found in a ship drawing office comprise:

Proportional divider, for transferring reduced or enlarged dimensions.

Planimeter, for calculating areas.

Integrator, for getting moment of inertia of any area.

Comptometer and other mechanical devices for adding, subtracting, multiplying, etc.; some of these being self-recording.

Slide rule, both of straight and Fuller type, for making computations.

Apparatus for making blue-prints either by sunlight or artificial light.

In ship drawing it is customary to make only preliminary pencil drawings, the finished drawing being in the form of an ink tracing on tracing cloth, from which blue-prints can be made.

Most of the areas to be calculated in shipbuilding are bounded on one or more sides by curves. These curves are or are very nearly parabolas of either the 1st, 2d, or 3d order. It is therefore usual to calculate the areas by means of one of Simpson's rules or by the trapezoidal rule. These rules are as follows:

Simpson's first rule.

$$A = \frac{h}{3}(y_1 + 4y_2 + 2y_3 + 4y_4 \; . \; . \; . \; . \; 4y_n + y_{n+1}).$$

To find the area of figure, as *ABCD* (Fig. 6).

Divide base into any convenient *even* number of equal spaces and erect ordinates. *The sum of end ordinates plus four times sum of even ordinates and two times sum of odd ordinates, multiplied by one-third the distance between ordinates, equals area.*

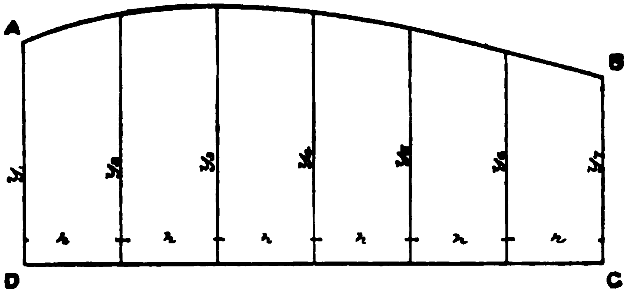

FIG. 6.

EXAMPLE.—A curvilinear area has ordinates 2 feet apart whose lengths are 1.55, 2.75, 4.45, 6.55, 8.60, 10.50, and 11.95 feet: to find area.

Number of Ordinates.	Length of Ordinate.	Simpson's Multipliers.	Function of Ordinates.
1	1.55	1	1.55
2	2.75	4	11.00
3	4.45	2	8.90
4	6.55	4	26.20
5	8.60	2	17.20
6	10.50	4	42.00
7	11.95	1	11.95
			118.80

Common interval $=$ 2 feet.

$\frac{1}{3}$ Common interval $= \frac{2}{3}$ foot.

Area $= 118.8 \times \frac{2}{3} = \frac{237.6}{3} = 79.2$ square feet.

Or Simpson's second rule.

NOTE.—In using this rule the number of intervals may be either odd or even, but must be a multiple of three.

$$A = \frac{3h}{8}(y_1 + 3y_2 + 3y_3 + 2y_4 + 3y_5 \ldots . 3y_n + y_{n+1}).$$

The sum of end ordinates plus two times sum of ordinates numbers 4, 7, 10, etc., plus three times sum of all other ordinates, multiplied by $\frac{3}{8}$ distance between ordinates, equals area.

EXAMPLE.—A curvilinear area has ordinates at a common distance of 2 feet whose lengths are 1.55, 2.75, 4.45, 6.55, 8.60, 10.50, and 11.75. To find area:

Number of Ordinates.	Length of Ordinate.	Simpson's Multipliers.	Functions of Ordinates.
1	1.55	1	1.55
2	2.75	3	8.25
3	4.45	3	13.35
4	6.55	2	13.10
5	8.60	3	25.80
6	10.50	3	31.50
7	11.95	1	11.95
		Sum of functions	105.50

Common interval $= 2$ feet.

$\frac{3}{8}$ Common interval $= \frac{3}{4}$ foot.

$$105.5 \times \frac{3}{4} = \frac{316.5}{4} = 79.125 \text{ square feet.}$$

NOTE.—When the curvature of a line forming boundary of an area is sharp, intermediate ordinates must be used, the spacing of the

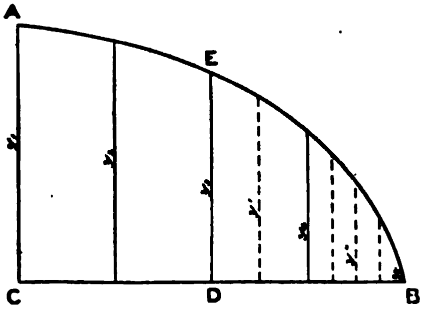

FIG. 7.

intermediate ordinates being a submultiple of the ordinary spacing.

Area DEB (Fig. 7) $= \frac{1}{3} \left(\frac{h}{2}\right) (y_3 + 4y' + 2y_4 + 4y'' + y_5)$ where $y_5 = 0$.

The 5-8 rule, applicable to curvilinear area contained between two consecutive ordinates is as follows:

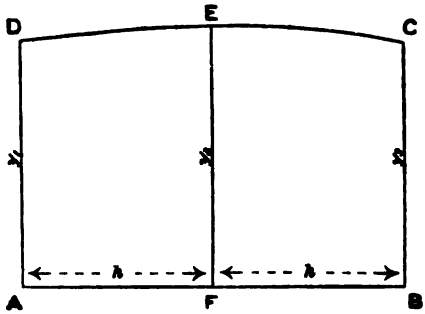

FIG. 8.

$$\text{Area } ADEF \text{ (Fig. 8)} = \frac{h}{12}(5y_1 + 8y_2 - y_3).$$

Eight times middle ordinate plus five times near end ordinate minus far end ordinate multiplied by 1/12 interval, equals area between first two ordinates.

Trapezoidal rule.—This rule is generally used by the Bureau of Construction and Repair of the U. S. Navy, in its calculations, but

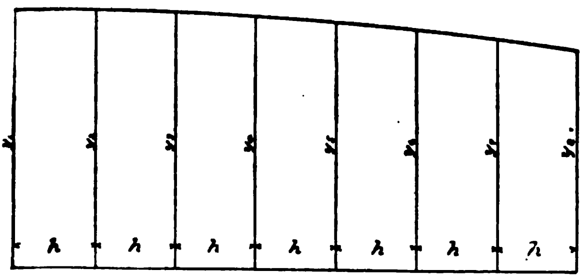

FIG. 9.

requires special care in spacing and measuring the ordinates. (See Fig. 9.)

$$A = h\ (\tfrac{1}{2}y_1 + y_2 + y_3 + y_4 + y_5 + y_6 + y_7 + \tfrac{1}{2}y_8),$$

or

Divide base into *any* convenient number of equal spaces and erect ordinates meeting the curve.

Sum of one-half the end ordinates plus sum of all other ordinates, multiplied by common interval, equals area.

This rule is based on assuming that each part of the area bounded by consecutive ordinates is a trapezoid, and the area of a trapezoid = height × ½ sum of bases, as the midshipman has learned in his geometry.

In the case of actual ship calculations, if we compute by one of the rules above the areas of the various equidistant waterlines, beginning with the keel, and use these values as ordinates at their corresponding drafts, we may plot a curve from which the area of any waterline, at any draft, may be taken as desired. Such a curve appears on the displacement scale (Plate II).

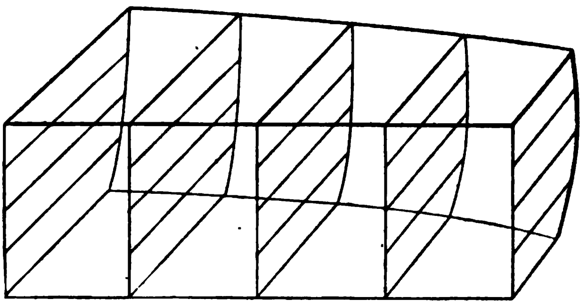

FIG. 10.

Volume of solid bounded by curved surface.—This is an ordinary requirement in ship calculations, as in finding volumes of coal bunkers and other compartments—the most important case being the underwater volumes of the ships.

In this case the volume is generally considered divided by a number of parallel planes equally spaced. These planes in ship building may usually either be horizontal or vertical, as shown in sketch. (Fig. 10.) The area of these planes is then determined by one of the above rules, and the results taken as ordinates of a curve of areas, the ordinates having the spacing of the parallel planes. This curve of areas may actually be drawn, as is sometimes desirable to check the fairness, and the area of curve then calculated as before, giving the volume; or the calculation may be made without

actually drawing the curve, as is generally done in the displacement calculation, to save time and space.

EXAMPLE.—The underwater portion of a vessel is divided by vertical sections 10 feet apart and these sections have the following areas: 0.4, 22.8, 48.9, 73.3, 88.5, 82.9, 58.8, 26.3, 4.0 square feet. To find volume:

Number of Section.	Area of Section.	Simpson's Multipliers.	Functions of Areas.
1	0.4	1	0.4
2	22.8	4	91.2
3	48.9	2	97.8
4	73.3	4	293.2
5	88.5	2	177.0
6	82.9	4	331.6
7	58.8	2	117.6
8	26.3	4	105.2
9	4	1	4
		Sum of functions	1218.0

$\frac{1}{3}$ Common interval $= \frac{10}{3}$

$\therefore$ volume $= 1218 \times \frac{10}{3} = \frac{12180}{3} = 4060$ cubic feet.

Displacement calculations.—As the underwater body of a ship is symmetrical about the fore and aft middle line plane, only one side is generally used.

The volume is divided, 1st, by equidistant planes parallel to the L. W. plane; 2d, by equidistant planes perpendicular to L. W. plane and to fore and aft middle line plane.

The area of these planes is calculated, and from them the volume. The volume calculated either way (*i. e.*, by first finding area of horizontal planes and then integrating or by first finding area of vertical planes and then integrating) should be the same, and the two results are used to check each other. The full details of this calculation as applied to ships, are made on special ruled forms for compactness and ready recording, and while presenting no difficulties are somewhat long and involved, and are not given here. They may be found if desired in detail in "Instructions for Standard Ship Calculations," issued by Bureau C. & R.

Displacement curve.—From dimensions obtained from the sheer draft, the volume of displacement to each of the consecutive water-

lines is calculated by one of the foregoing rules (in the U. S. Service, trapezoidal rule), and the displacements so obtained are set up on a certain scale above a base line, each at a distance from an origin representing the draft of the water-plane to which the displacement is calculated. This gives a series of spots through which a curve may be run, and from this curve, the displacement at any given draft may be obtained.

In practice, instead of making separate calculations to each waterline, the whole calculation is combined into one, suitably arranged so that displacements to the several waterlines are separately determined, thus saving time and space.

In actual ship calculations certain projecting portions of the hull fall outside the fair line of hull. These are called *appendages*, are separately calculated and added to the general result to obtain the total.

For curves of displacement, see Plate II.

To read curve: When the ship is floating at a waterline not parallel to the designed load waterline, and it is desired to obtain the displacement, it is customary to read draft aft and forward, take mean, and find displacement from curve corresponding to this mean draft; but the reading obtained from applying the mean draft to the curve is not exactly correct and requires to be corrected for a certain difference of draft forward and aft. In practice, this is done by means of curve of "Additional displacement for one foot change of trim by stern," shown on displacement scale whose deduction is complicated and therefore not given. (It may be found, if desired, on page 14 of "Instructions for Standard Ship Calculations," issued by the Bureau of Construction and Repair.)

Displacement in fresh water.—This only varies from that in salt water in that the displacement in tons is determined from the volume by dividing by 36 instead of 35.

A ship whose volume of underwater hull is 4060 cubic feet would have a displacement in salt water of $4060 \div 35 = 116$ tons.

If this ship's underwater volume in fresh water were 4060 cubic feet, her displacement would be $4060 \div 36 = 112.77$.

Curve of tons per inch immersion.—This is a curve, representing at various drafts, the tons (in salt water) of displacement per inch of depth of hull at that draft.

If A = area, in square feet, of water-plane at any draft,

$A \times \frac{1}{12}$ = volume, in cubic feet, of layer 1 inch thick at that draft;

$A \times \frac{1}{12} \times \frac{1}{35}$ = displacement, in tons in salt water, of this volume;

Or tons per inch immersion at any draft $= \dfrac{A}{420}$ where A is area of waterline at that draft.

This is calculated for the various waterlines and plotted in form of a curve from which the tons per inch at any desired draft may be obtained.

Curves of areas of midship section.—The area of the midship section up to each of the waterlines is calculated from ordinates

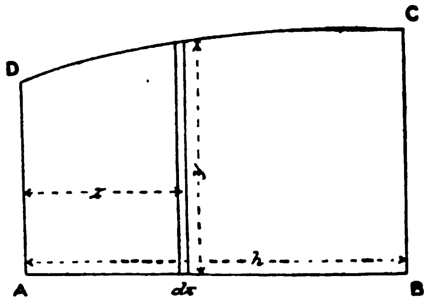

FIG. 11.

measured from sheer draft, and the results obtained are plotted as a curve, which should be a fair curve.

Moment and C. G. of area.—The geometrical moment of an area about a given axis is the product of the area into the perpendicular distance of C. G. from the axis. Therefore, if we know the moment of an area about an axis, and the area, we can find the distance of the C. G. from the axis.

Consider Fig. 11.

Area infinitesimal strip $= ydx$;

Moment about AD of this strip $= y \times dx \times x$.

Moment whole area about $AD = \int_0^h y \times dx \times x$.

But the expression for area $= \int_0^h ydx.$

Therefore, C. G. from $AD = \dfrac{\int_0^h y \times dx \times x}{\int_0^h ydx}.$

The practical calculation expression for $\int_0^h y\ dx$ is, as we have seen above, one of Simpson's rules or the trapezoidal rule, and the practical calculation expression for $\int_0^h y \times dx \times x$ will be seen from the following example:

A load water-plane has the following semi-ordinates: 0, 10.2, 20.0, 27.4, 32.1, 34.0, 33.8, 31.7, 27.6, 20.6, 9.4. The ship is 395 feet long. To find area and position of C. G. relative to middle ordinate:

Number of Ordinate.	Length of Ordinate.	Simpson's Multipliers.	Functions of Ordinates.	No. of Interval from Mid. Ord.	Products for Moments.
1	0.0	1	0.0	5	0.0
2	10.2	4	40.8	4	163.2
3	20.0	2	40.0	3	120.0
4	27.4	4	109.6	2	219.2
5	32.1	2	64.2	1	64.2
6	34.0	4	136.0	0	566.6
7	33.8	2	67.6	1	67.6
8	31.7	4	126.8	2	253.6
9	27.6	2	55.2	3	165.6
10	20.6	4	82.4	4	329.6
11	9.4	1	9.4	5	47.0
			732.0		863.4

Common interval $= \frac{395}{10} = 39.5$ feet.

$\therefore$ Half area $= \frac{39.5}{3} \times 732 = 9638$ square ft.

C. G. from the middle ordinate is $\dfrac{(863.4 - 566.6)}{732} \times 39.5$ or 16.01.

NOTE.—C. G. is obtained by working with functions and thus saving time.

It should be noted in all cases of calculations that the tables are so arranged as to prevent useless duplication of work, the multiplications being made at the end, and due cognizance being taken of cancellations.

To find position of C. G. of an area bounded on one side by a curved line, contained between two consecutive end ordinates, with respect to near end ordinate:

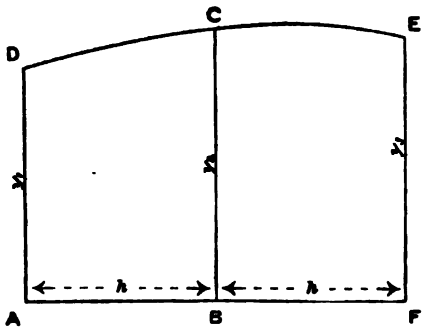

FIG. 12.

Moment of $ABCD$ (Fig. 12) about $AD = \frac{h^2}{24}(3y_1 + 10y_2 - y_3)$.

The curved line being considered as a parabola of the second order.

EXAMPLE.—A curve has ordinates 11, 10, 8 feet long, common interval 4 feet. Find position of C. G. of portion between first two ordinates with respect to near end ordinate.

	Areas.		Moments.	
Ordinates.	Simpson's Multipliers.	Functions.	Simpson's Multipliers.	Functions.
11	5	55	3	33
10	8	80	10	100
8	−1	−8	−1	−8
		127		125

$$\text{Moment} = 125 \times \frac{(4)^2}{24}$$

$$\text{Area} = 127 \times \frac{4}{12}$$

$$\therefore \text{ C. G.} = \frac{125 \times \cancel{16}^{\,2} \times \cancel{12}}{127 \times \cancel{4} \times \cancel{24}_{\,2}} = \frac{250}{127} = 1.968 \text{ feet.}$$

Position of C. G. of curvilinear area with respect to its base:

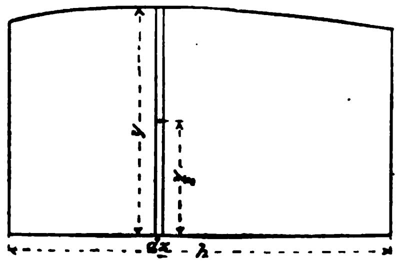

FIG. 13.

(See Fig. 13.)

$$\text{Area} = \int_o^h y\,dx$$

$$\text{Moment about base} = \int_o^h \frac{y}{2} \cdot y\,dx = \tfrac{1}{2}\int_o^h y^2 dx.$$

The practical calculation method of doing this is to apply Simpson's or trapezoidal rule to y^2, *i. e.*, to the square of the measured ordinates.

Having determined the longitudinal location of the C. G. of the various equidistant water-planes, their positions may be plotted to a suitable scale and a fair curve drawn through the spots which represents the locus of the positions of C. G. of water-planes and from which the location of the C. G. of any water-plane may be determined. Such a curve appears in the displacement scale, Plate II.

To find center of gravity of solid bounded by curved surface and plane.—From above we know that in finding the volume of a solid we use the usual rules as in finding area of a plane, except that

as ordinates we use areas instead of linear dimensions. In a similar manner, the principle used in finding the C. G. of an area applied to this problem, using areas instead of linear dimensions, will permit us to find the C. G. of a solid body.

EXAMPLE.—A coal bunker has sections 17′ 6″ apart and the areas of the sections are 99, 124, 138, 136, 123 square feet.

To find the volume of the bunker and the location of its C. G. relative to the end:

Area.	Simpson's Multiplier.	Functions of Areas.	Number of Interval from End.	Products for Moments.
99	1	99	0	0
124	4	496	1	496
138	2	276	2	552
136	4	544	3	1632
123	1	123	4	492
		1538		3172

$$\text{Volume} = 1538 \times \tfrac{1}{3} \times \tfrac{35}{2} = 8971.66.$$

$$\text{Moment} = 3172 \times \tfrac{1}{3} \times \tfrac{35}{2} \times \tfrac{35}{2}.$$

$$\therefore \text{Dist. C. G. from end} = \tfrac{3172}{1538} \times \tfrac{35}{2} = 36.09 \text{ feet.}$$

In making all calculations of this character, an approximate checking will insure against grievous mistakes. For illustration:

Considering the above bunker we see it to be $4 \times 17\tfrac{1}{2}$ feet long. An examination of the sections shows it to be fuller at the far end than at the near end, which would indicate that the C. G. would be a little more than half the distance from the near end, which agrees closely with our result.

Calculation of position of C. B.—We have seen this point defined, and it is dependent solely on the form of the underwater portion of the ship. It is therefore evident that the determination of its location is the same general problem as that illustrated in the preceding paragraph.

As a ship is symmetrical about the longitudinal center-line plane, the C. B. evidently lies in that plane. It therefore remains to determine its position:

(1) Above base.

(2) Relative to fore and aft length.

To find C. B. in fore and aft direction having given areas of equidistant transverse sections.—The underwater portion of a vessel is divided by transverse sections 10 feet apart of the following areas: 0.3, 22.8, 48.9, 73.3, 88.5, 82.9, 58.8, 26.3, 4.0 square feet. Find the position of the C. B. relative to middle section:

Number of Station.	Area.	Simpson's Multiplier.	Function of Area.	Number of Interval from Middle.	Product for Moments.
1	0.3	1	0.3	4	1.2
2	22.8	4	91.2	3	273.6
3	48.9	2	97.8	2	195.6
4	73.3	4	293.2	1	293.2
5	88.5	2	177.0	0	763.6
6	82.9	4	331.6	1	331.6
7	58.8	2	117.6	2	235.2
8	26.3	4	105.2	3	315.6
9	4.	1	4.	4	16.
			1217.9		898.4

$$\text{Volume} = 1217.9 \times \frac{10}{3}$$

$$\text{Excess products aft} = 898.4 - 763.6 = 134.8.$$

$$\text{Moment aft} = 134.8 \times \frac{10}{3} \times 10.$$

$$\text{C. B. aft} = \frac{134.8}{1217.9} \times \frac{10}{\cancel{3}} \times \cancel{10} \times \frac{\cancel{3}}{\cancel{10}} = 1.106 + \text{feet.}$$

To calculate C. B. in vertical direction.—Same principle may be used, taking areas of waterlines instead of sections.

To find C. B. in vertical direction.—*The area of a displacement curve to any waterline divided by the displacement to that waterline gives the distance of the center of buoyancy of the displacement below that waterline.*

Consider the curve NeL (Fig. 14), which is a displacement curve, plotted in the ordinary way, with drafts measured along the line NW and displacements in the direction WL.

In this case NW is the mean draft and WL the corresponding displacement under consideration.

Take two level lines ge and g^1e^1 a small distance dz apart.

Call the area of waterline, at level ge, A sq. ft. and the distance of this water-plane below plane WL, z.

The volume between the waterlines ge, g^1e^1 will be Adz.

The moment of this layer about plane WL will be $Az\ dz$.

The difference in lengths of ge and g^1e^1 is evidently the weight of the volume of water between these two waterlines, or $\dfrac{Adz}{35}$.

Draw el and e^1l^1 vertically as shown,

The width of strip e^1l^1 is $\dfrac{Adz}{35}$ and its area is $\dfrac{Az\ dz}{35}$.

The area of the curve will be the sum of the areas of all such strips, or $\int\dfrac{Az\ dz}{35}$.

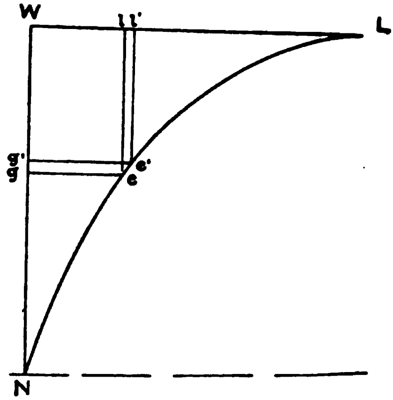

FIG. 14.

The moment of the volume of displacement about the water-plane WL is $\int Adz \times z$ and the distance of center of buoyancy below the water-plane is given by dividing this moment by the displacement in cubic feet, or $\int\dfrac{Az\ dz}{WL \times 35}$. (See figure.)

But the area of the curve divided by the displacement in tons is, as we have seen, $\dfrac{\int\frac{Az\ dz}{35}}{WL}$, which is the same thing.

Curves of locus of center of buoyancy.—Having seen the method of calculating the position of center of buoyancy or C. B. it remains to be seen how these are plotted on the curves.

The longitudinal position of C. B. is calculated to the various waterlines with reference to some chosen section, and its position plotted from the vertical reference line. (See Plate II.)

The vertical position of C. B. is calculated for the volumes to the various waterlines with reference to that waterline.

The spots found are then plotted thus: (Fig. 15.)

Through origin is drawn a line OL at 45° intersecting the various waterlines. Where this line intersects the waterlines, the distance of C. B. below that waterline is set down, giving spots as B_1, B_2, B_3, B_4 through which a curve can be passed.

Therefore, to find vertical position of C. B., run across the waterline at which it is desired until the 45° line is met, then measure down for the distance of C. B. below waterline at this draft.

We have seen above how the curves of displacement, locus of

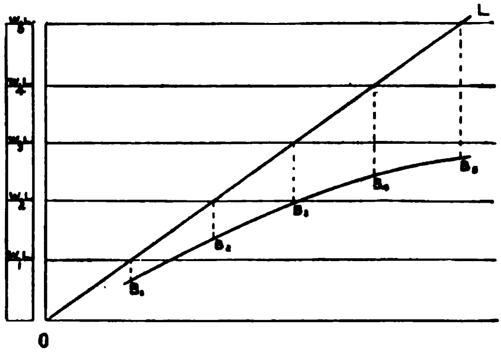

FIG. 15.

center of buoyancy, areas of water-planes, &c., are calculated and plotted.

For actual ships, after having made the calculations, all of which are combined into one general form, the results of these calculations are plotted to form a *displacement scale.* This displacement scale shows the following curves: See Plate II.

1. Displacement in salt water.
2. Displacement in fresh water.
3. Vertical position of center of buoyancy.
4. Longitudinal position of center of buoyancy.
5. Total area of water-planes.
6. Longitudinal position of C. G. of waterlines.
7. Tons per inch immersion.

8. Whole area of midship section.
9. Transverse metacenter above center of buoyancy.
10. Moment to trim ship one inch.
11. Additional displacement for 1 foot change of trim by stern.
12. Area of wetted surface.
13. Outline of midship section.

Difference in draft of water when floating in sea water and when floating in river water.—The weight per cubic foot of sea water is greater than that of fresh water, hence a vessel on passing from river to sea water, the weight remaining constant, will rise in the water and have a greater freeboard.

Sea water weighs 64 lbs. per cubic foot.

Fresh water weights 63 lbs. per cubic foot.

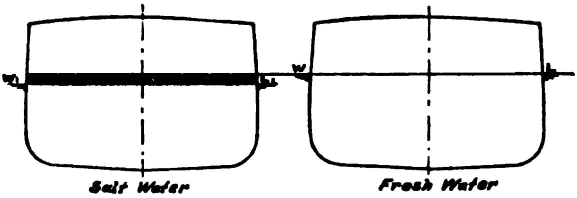

FIG. 16.

Consider Fig. 16.

$W =$ weight of ship in tons.

$T =$ tons per inch immersion at W^1L^1 in salt water.

$x =$ difference in draft between waterlines in salt and fresh water.

In fresh water $\frac{W \times 2240}{63} =$ volume displacement.

In sea water $\frac{W \times 2240}{64} =$ volume displacement.

$$\text{Volume layer} = \frac{W \times 2240}{63} - \frac{W \times 2240}{64} = \frac{W \times 2240}{63 \times 64}.$$

$$\text{Now volume layer} = x \times T \times \frac{2240}{64}.$$

$$x \times T \times \frac{\cancel{2240}}{\cancel{64}} = \frac{W \times \cancel{2240}}{63 \times \cancel{64}}$$

$x = \frac{W}{63\,T}$ inches.

Sinkage caused by bilging a central compartment.—If we take a simple case of a box-shaped vessel having watertight bulkheads at EG and HF and consider a hole made below the waterline—as in Fig. 17.

If the weight of the ship is $= W$
The displacement must $= W$.

This buoyancy must be the same after bilging as before, and the lost buoyancy must be made up by the vessel sinking in the water until the original buoyancy is again reached.

If W^1L^1 be the new waterline, d^1 the new draft, then as it is rectangular, $WL \times b$ (or breadth) $\times d = W^1L^1 \times b \times d^1 - NO \times b \times d^1$

Or $WL \times b \times d = d^1 \times b\ (W^1L^1 - NO)$.

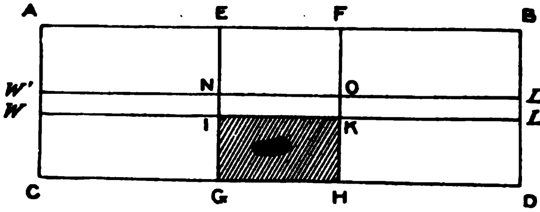

FIG. 17.

(A) $$d^1 = \frac{WL \times d \times b}{(W^1L^1 - NO)\,b}.$$

(B) $$\text{Sinkage} = d^1 - d = \frac{WL \times d \times b - (W^1L^1 - NO)\,d \times b}{(W^1L^1 - NO)\,b}.$$

But as $W^1L^1 = WL$, (B) $= \dfrac{NO \times d \times b}{(W^1L^1 - NO)\,b}$.

If the bilged compartment contains stores or other solids, the amount of water entering would be less than if the compartment were quite empty and the sinkage correspondingly less.

The general expression for sinkage from formula **(B)** is:

$$\text{Sinkage} = \frac{\text{volume of lost buoyancy in cubic feet}}{\text{area of intact water-plane in sq. ft.}}$$

The above assumes the bilged compartment in the middle of the length. Where a compartment is forward or aft, trim would occur which will be treated of later.

Velocity of inflow of water into vessel on bilging.

A = area of hole in square feet.

d = distance of C. G. of hole below surface, in feet.

V = initial rate of flow of water in feet per second.

$V^2 = 2gd$ where g = gravity = 32.

$\therefore V = \sqrt{2 \times 32d} = 8\sqrt{d}.$

$\therefore$ Volume of water per second $= A \times 8\sqrt{d}.$

Area of wetted surface.—This is an ordinary ship calculation and is done in detail in the regular ship calculation. An approximate method is by Kirk's Analysis, which is not treated here, as it has been given elsewhere in the course. Another and perhaps better approximation is from the following formula, given by Naval Constructor D. W. Taylor, U. S. N.:

Approximate area of wetted surface $= C\sqrt{D \times L} = \ldots$ feet.
Where D = Displacement in tons
L = Mean immersed length in feet.

Values of C for various ratios of molded beam (B) to molded draft (H) are given below:

B÷H	C	B÷H	C	B÷H	C	B÷H	C
2.0	15.63	2.4	15.15	2 8	15.55	3.2	15.71
2.1	15.58	2.5	15.50	2.9	15.58	3.3	15.77
2.2	15.54	2.6	15.51	3.0	15.62	3.4	15.83
2.3	15.51	2.7	15.53	3.1	15.66	3.5	15.89

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Theoretical Naval Architecture, Thearle.
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Theorie du Navire, Pollard & Dudebout.

PROBLEMS.

Simpson's 1st Rule.

(1) A curvilinear area has ordinates at a common distance apart, of 3 ft., the lengths being 2.45, 3.65, 5.35, 7.45, 9.50, 11.40, and 12.85 feet, respectively. Find the area of the figure in square feet.

(2) Find the area in square feet of a water-plane whose half ordinates are 0.2, 5.9, 10.5, 13.1, 14.2, 14.5, 14.5, 14.0, 12.6, 9.8, and 0.2 feet, respectively. The common interval is 15 feet.

(3) What is the area of a bulkhead whose half ordinates are 0.3, 6.0, 8.5, 10.0, 11.0, 11.8, 12.3, 12.7, and 12.9 feet, respectively, and common interval 2 feet?

Simpson's 2d Rule.

(4) Find the area in square feet of a curvilinear area having ordinates at a common distance apart, of 2.5 ft., the lengths of the ordinates being 3.50, 4.70, 5.60, 6.30, 7.00, 7.50, and 7.90 feet. Use Simpson's 2d Rule.

(5) A curve has the following ordinates 1 ft. 4 in. apart: 10.86, 13.53, 14.58, and 15.05, respectively. Find its area.

(6) The semi-ordinates of a vessel's midship section are 26.6, 26.8, 26.8, 26.4, 25.4, 23.4, and 18.5 feet, respectively, the ordinates being 3 feet apart. Below the lowest ordinate there is an area for one side of the section of 24.6 square feet. Find the area of the midship section, using Simpson's 2d Rule.

Fractional Intervals.

(7) Find the area of the plane figure which has ordinates as follows: 0.2, 2.1, 4.5, 7.0, 9.1, 12.3, 14.0, 14.5, and 14.3 feet, respectively. The intervals between ordinates are 15, 15, 15, 15, 30, 30, 30, and 30 feet, respectively.

(8) A portion of a ship's waterline has half ordinates of 0.1, 1.3, 2.4, 5.6, 11.0, 13.7, and 13.4 feet, and the spacing of the ordinates is 10, 10, 10, 30, 30, and 30 feet, respectively. Find the area in square feet, using Simpson's 2d Rule and fractional multipliers where required.

(9) Find the area of a curvilinear figure having ordinates of 0.4, 6.0, 11.8, 21.0, 26.2, 28.4, 29.0, 29.0, 28.0, 26.8, 25.4 feet, with intervals of 12, 12, 24, 24, 24, 24, 24, 24, 12, and 12 feet, respectively, between the ordinates.

5-8 Rule.

(10) A curvilinear area has ordinates 4 ft. apart, of length 10.2 10.5, and 13.8 ft., respectively. Find the area between the first and second ordinates.

(11) Find the area between the second and third ordinates in the problem above.

(12) A watertight bulkhead has half ordinates of 7.4, 8.7, and 9.4 ft. at distances of 8, 12, and 16 ft., respectively, from the keel. Find the total area in square feet between the 12 and 16 ft. lines.

Trapezoidal Rule.

(13) Find the area of a plane curvilinear figure whose semi-ordinates are 0.2, 2.9, 5.3, 7.5, 9.2, 10.7, 11.8, and 12.6 ft., respectively, with a common interval of 2 ft.

(14) The load water-plane of a ship has semi-ordinates of 0, 5.0, 9.6, 12.6, 14.4, 14.5, 14.4, 13.5, 11.3, 6.5, and 0.5 ft., respectively, with a common interval of 14.5 ft. Find the area in square feet, using the trapezoidal rule.

(15) Find the area of a bulkhead whose half ordinates are 0.0, 2.75, 5.50, 8.20, 10.60, and 13.20 ft., respectively, and distance between consecutive ordinates 2.5 ft.

Volume.

(16) A coal bunker has sections 15 feet apart, and the areas of these sections are 93, 118, 132, 130, and 117 square feet, respectively. Find the volume of the coal bunker in cubic feet, and the capacity in tons, allowing 43 cubic feet per ton.

(17) The curve of sectional areas of a ship's under body has ordinates of 1.5, 23.9, 50.0, 74.4, 89.6, 84.0, 59.9, 27.4, and 5.1 square feet, respectively, spaced 12 feet apart. Find the volume in cubic feet.

(18) What is the capacity in cubic feet of a tank which has sectional areas of 19.4, 18.5, 17.2, 15.6, 13.6, 10.9, and 6.5 square feet, respectively, the distance between sections being 2.5 feet?

Tons per inch.

(19) The area of a water-plane is 9648 square feet. Find the tons per inch of immersion. Supposing 50 tons placed on board, how much would the vessel sink?

(20) Find the tons per inch at a water-plane which has half ordinates of 0.3, 2.3, 4.5, 6.4, 7.7, 8.6, 9.0, 9.2, 9.3, 9.1, 8.8, 8.4, 7.6, 6.2, and 3.5 feet, respectively, the ordinates being 6.5 feet apart.

(21) The tons per inch immersion of a vessel when floating in salt water at a certain water-plane is 41.8. What is the area of this plane?

Longitudinal C. G. of water-plane.

(22) The semi-ordinates of the load water-plane of a vessel 320 feet long are, commencing from forward, 0, 8.8, 15.8, 19.6, 21.3, 22.8, 22.7, 21.0, 19.0, 14.7, and 0.2 feet, respectively. Find the distance of the center of gravity from the middle ordinate.

(23) The load waterline of a ship has semi-ordinates of 0.1, 10.3, 20.1, 27.5, 32.2, 34.0, 33.9, 31.8, 27.7, 20.7, and 9.5, respectively, at intervals of 40 feet. Find the area and the distance of the C. G. from the middle ordinate.

(24) The semi-ordinates of a water-plane, commencing from the after end, are 4.1, 9.1, 13.3, 16.8, 19.5, 21.6, 23.2, 24.4, 25.1, 25.4, 25.5, 25.2, 24.3, 22.8, 20.7, 17.7, 14.3, 10.4, 6.1, 2.2, and 1.1 feet. The distance apart is 18 feet. Find the position of the center of gravity in relation to the middle ordinate.

C. G. between consecutive end ordinates.

(25) A curve has ordinates 12, 11, and 9 feet long, 5 feet apart. Find the position of the center of gravity of the portion between the first two ordinates with respect to the end ordinate.

(26) A bulkhead has half ordinates of 0.6, 5.6, and 8.3 feet, 4 feet apart, the first being at the keel. Find the distance above the keel of the center of gravity of the portion below the 4-foot line.

(27) A curve has ordinates of 14, 12, and 9 feet, 3 feet apart. Find the distance of the center of gravity of the area between the first and second ordinates, from the first ordinate.

(28) The ordinates of an inclined water-plane of a vessel are 6 feet apart, and the lengths are 0.3, 2.3, 4.5, 6.4, 7.7, 8.6, 9.0, 9.2, 9.3, 9.1, 8.8, 8.4, 7.6, 6.2, and 3.5 feet, respectively. Calculate the distance of the center of gravity from the centerline.

(29) Find the area and transverse position of the center of gravity of "half" a water-plane, the ordinates in feet being 0.5,

6, 12, 16, 12, 10, and 0.5, respectively, the common interval being 15 feet.

(30) An area bounded by a curve and a straight line is divided by ordinates 4 feet apart, of the following lengths: 0, 12.5, 14.3, 15.1, 15.5, 15.4, 14.8, 14.0, and 0 feet, respectively. Find the position of the center of gravity relative to the base.

(31) The ordinates given below are for one-half of the main cargo hold of a vessel. Find the cubic capacity of the hold, and the distance of the center of gravity of one-half from the center-line. The frame spacing is 3 feet, and the distance between level lines is 4 feet 6 inches.

ORDINATES IN FEET AT FRAMES—NUMBERS.

Level Lines	15	20	25	30	
No. 1	4.8	9.0	12.7	14.2	14.4
No. 2	9.8	15.0	18.7	19.9	20.1
No. 3	12.7	17.6	20.5	21.5	21.6
No. 4	14.5	19.0	21.2	21.7	21.8
No. 5	15.7	19.6	21.3	21.7	21.8

(32) From the particulars given below, find the longitudinal and transverse positions of the center of gravity of the body which is a solid bounded by a plane and curved surface.

ORDINATES IN FEET AT SECTIONS—NUMBERS.

	1	2	3	4	5
No. 1 W. L.	0.2	7.4	11.0	9.3	2.0
No. 2 W. L.	0.2	5.3	10.5	6.5	0.3
No. 3 W. L.	0.2	2.0	7.6	2.6	0.3

(33) The curve of sectional areas of a side bunker has ordinates of 142, 170, 181, 176, and 165 square feet, respectively, and the distance between ordinates is 10 feet. Find the longitudinal and transverse positions of the center of gravity of the bunker, also the capacity in tons, one ton of coal being equal to 43 cubic feet.

(34) The tons per inch of a ship's displacement at waterlines 4 feet apart, commencing at the L. W. L., are 45.3, 43.7, 41.5, 38.5, 34.3, and 0, respectively. Find the position of the C. B. below the L. W. L.

(35) A vessel is 180 feet long, and the transverse sections from the load waterline to the keel are semi-circles. Find the longitudinal position of the center of buoyancy, the ordinates of the load water-plane being 1, 5, 13, 15, 14, 12, and 10 feet, respectively.

(36) From the particulars given below, find the fore and aft and vertical positions of the center of buoyancy of the vessel. The vessel is 120 feet long and the draft is 9 feet.

HALF ORDINATES IN FEET.

Waterlines	Stem	Section 2	Section 3	Section 4	Sternpost
L.W.L.	0.2	7.4	11.0	9.3	2.0
2W.L.	0.2	5.3	10.5	6.5	0.3
1W.L.	0.2	2.0	7.6	2.6	0.3
Keel	0.2	0.2	0.2	0.2	0.3

(37) A vessel is 500 feet long, 60 feet broad, and floats at a mean draft of 25 feet when in salt water. Make an approximation to her draft when she passes into river water. (Coefficient of displacement 0.5; coefficient of L. W. P. 0.6.)

(38) A vessel floats at a certain draft in river water, and when floating in sea water without any change in lading, it is found that an addition of 175 tons is required to bring the vessel to the same draft as in river water. What is the displacement after the addition of the weight named?

(39) A ship floats at a draft of 28 ft. in river water. The weight of the ship is 16,000 tons and the area of the load waterline is 23,500 square feet. What is the draft of the same ship in sea water?

(40) A vessel in the form of a box, 100 feet long, 10 feet broad and 20 feet deep, floats at a draft of 5 feet. Find the draft if a central compartment 10 feet long is bilged below water.

(41) A box-shaped vessel 150 feet long by 20 feet broad and 15 feet deep floats at a draft of 10 feet. Find the length of a central compartment which, when bilged, will not sink her more than 2 feet.

(42) A box-shaped vessel 120 feet long, 20 feet broad, and 16 feet deep, floats at a draft of 12 feet when a midship compartment 20 feet long is open to the sea. Find the draft when this compartment is closed and empty.

CHAPTER V.

CONDITIONS OF EQUILIBRIUM.

Conditions that must obtain in case of ship floating at rest in water.

(1) The displacement must equal the weight of ship with everything on board.

(2) The downward force of the weight, from definition of C. G., must be considered as acting through C. G.

(3) The upward force of buoyancy, from definition of C. B., must act upward through C. B.

C. B. and C. G. must be in same vertical line, otherwise there will exist a couple tending toward rotation until this condition is realized.

Statical stability.—The *statical stability* of a ship is the tendency she has to assume the upright position when inclined away from that position, and is due to the conditions outlined above.

Stable equilibrium exists when, if the ship is inclined from her position of rest, she tends to return to it.

Unstable equilibrium exists when, if the ship is inclined from her position of rest, she tends to go farther away from it.

Neutral equilibrium exists when, if the ship is inclined from her position of rest, she neither tends to return to the position of rest, nor to move farther away from it.

Transverse metacenter we have had defined above. To find this point we proceed as follows:

(*A*) in Fig. 18, following, represents a cross-section of a ship. (*B*) in Fig. 18 represents the load water-plane in plan.

Now consider the ship inclined through a small angle, bringing the waterline, Fig. (*A*) to the position W^1L^1. W^1L^1 will intersect WL at the point O or at center.

NOTE.—This is not absolutely accurate except for small angles. The proof as to the location of the point of intersection is of some length, and the student has not time to go into it.

In general.—*If a floating body is slightly inclined and maintains the same volume of displacement, the new water-plane will intersect the old water-plane in a line through the C. G. of the original water-plane.*

Now the center of buoyancy, B, will, due to change of form of immersed volume, move to a point, as B^1

Let $r =$ half breadth.

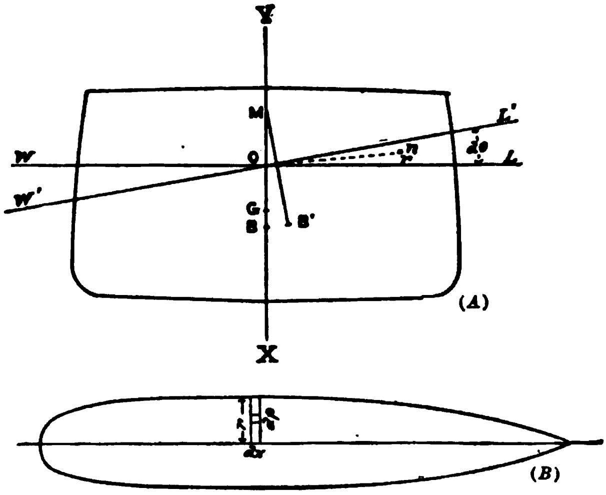


FIG. 18.

As the inclination is small, say $d\theta$

Area of triangle $OLL^1 = \frac{1}{2}r \times rd\theta$

Moment of area $OL^1L =$ area $\times$ distance C. G. from O

$$= \frac{r}{2} \times rd\theta \times on$$

$$\text{but } on = \tfrac{2}{3}\, r \cos \frac{d\theta}{2},$$

$$\therefore \text{moment of area} = \tfrac{2}{3}\, r \cos \frac{d\theta}{2}\left(\frac{r^2}{2}\, d\theta\right)$$

$$= \frac{r^3}{3} \cos \frac{d\theta}{2}\, d\theta.$$

Now, in the case of ships, the cross-section is symmetrical about vertical axis through O.

$\therefore$ Moment of area $WOW^1 =$ moment area LOL^1

(1) for whole ship total change of moment $=$

$$\int 2 \times \frac{r^3}{3} \cos \frac{d\theta}{2} \, d\theta \, dx.$$

(dx being the increment in direction of length).

But (1) $= V \times BB^1$

But $BB^1 = BM \sin d\theta$

$$\therefore \int 2 \frac{r^3}{3} \cos \frac{d\theta}{2} \, d\theta dx = V \times BM \sin d\theta$$

as $d\theta$ is small, $\sin d\theta = d\theta$ and $\cos \frac{d\theta}{2} = 1.$

$$\therefore V \times BM d\theta = \int \frac{2r^3}{3} d\theta \, dx,$$

$$\text{or } V \times BM = \int \frac{2r^3}{3} dx,$$

$$\text{or } BM = \frac{\int \frac{2r^3}{3} dx.}{V} .$$

Now $\int \frac{2}{3} r^3 dx$ is the expression for moment of inertia of the water-planes. See Figure 18 above we find

Increment area $= d\rho \times dx$

Moment increment $= \rho d\rho dx$

Inertia increment $= \rho^2 \times d\rho dx$

Inertia $\frac{1}{2}$ W. P. $= \int_o^L \int_o^r \rho^2 d\rho dx$

Total inertia $= \int_o^L \frac{2}{3} r^3 dx$

$\therefore$ the expression generally given is B. M. $= \frac{I}{V}$ where B. M. is the vertical distance from center of buoyancy to metacenter.

I is moment inertia of water-plane about its center line.

V is volume of displacement.

EXAMPLE.—The semi-ordinates 16.6 feet apart of a water-plane are 0.2, 2.3, 6.4, 9.9, 12.3, 13.5, 13.8, 13.7, 12.8, 10.6, 6.4, 1.9, 0.2.

If displacement up to this waterline is 220 tons, find value of B. M.

Number of Ordinate.	Semi-ordinate of Water-plane.	Cubes of Semi-ordinates.	Multipliers.	Functions of Cubes.
1	0.2	..	1	..
2	2.3	12.1	4	48.4
3	6.4	262.1	2	524.2
4	9.9	970.3	4	3881.2
5	12.3	1860.8	2	3720.6
6	13.5	2460.3	4	9841.2
7	13.8	2628.0	2	5256.0
8	13.7	2571.3	4	10285.2
9	12.8	2097.1	2	4194.2
10	10.6	1191.0	4	4764.0
11	6.4	262.1	2	524.2
12	1.9	6.8	4	27.2
13	0.2	..	1	..
				43066.4

Moment inertia $= 43066.4 \times \frac{2}{3} \times \frac{16.6}{3}$

B. M. $= 43066.4 \times \frac{2}{3} \times \frac{16.6}{3} \div 220 \times 35 = 20.6$ feet.

We are therefore able, by dividing the moment of inertia of the several water-planes by the volume up to those water-planes to obtain the value of B. M., and by setting it up from our curve of C. B. to get a curve of M.

We may similarly demonstrate that the value of *longitudinal* B. M. is I about a transverse line at middle of length divided by volume.

The I in this direction is given by a formula of the form $\int rx^2dx$ as seen by inspecting Fig. 18 above.

The practical application of this rule is illustrated by the following example:

It is usual to find Moment of Inertia about ordinary midship ordinate. If we call this I and if y be the distance of *centre of flotation,* which is C. G. of water-plane, from midship ordinate, then $I = I_0 + Ay^2$ or $I_0 = I - Ay^2$.

If Disp't be 91.6 tons, interval 7.1 feet.

Number of Ordinate.	Semi-ord. of L. W. P.	Multipliers.	Products for Areas.	Multipliers for Moments.	Products for Moments.	Multipliers for I.	Products for I.
1	0.00	½	0.00	5	0.00	5	00.00
1½	1.37	2	2.74	4½	12.33	4½	55.49
2	2.67	1½	4.01	4	16.04	4	64.16
3	4.87	4	19.48	3	58.44	3	175.32
4	6.31	2	12.62	2	25.24	2	50.48
5	6.85	4	27.40	1	27.40	1	27.40
6	7.21	2	14.42	0	139.45		
7	7.15	4	28.60	1	28.60	1	28.60
8	6.87	2	13.74	2	27.48	2	54.96
9	6.33	4	25.32	3	75.96	3	227.88
10	5.08	1½	7.62	4	30.48	4	121.92
10½	3.56	2	7.12	4½	32.04	4½	144.18
11	0.71	½	.35	5	1.75	5	8.75
			163.42		196.31		959.14
					139.45		
					56.86		

Area $= 163.42 \times \frac{1}{3} \times 7.1 \times 2 = 773.5$ square feet.

C. G. from ordinate No. 6 is $\frac{56.86 \times 7.1}{163.42} = 2.47$ feet.

$I = 959.14 \times \frac{1}{3} \times 7.1 \times (7.1)^2 \times 2 = 228{,}858.$

The multiplication above being: (a) By $\frac{1}{3}$ common interval to complete Simpson's rule.

(b) By square of common interval to complete integration for inertia.

(c) By two for both sides.

∴ Moment inertia of water-plane is

$$I_0 = 228{,}858 - (773.5 \times 2.47^2)$$
$$= 224{,}139$$

Now as $BM = \frac{I}{V}$,

$$BM = \frac{224{,}139}{91.6 \times 35} = 69.9 \text{ feet.}$$

We now come to the consideration of the question of transverse inclinations. We have had metacenter or M, defined; we have seen how its location may be determined.

Fig. 19, below, represents a section of a ship steadily inclined at a small angle from its normal or upright position by some external force.

As the weight of the vessel has not changed, the volume of displacement must be unchanged. We must assume that no weights on board shift, therefore the C. G. remains in the same position as before.

The shape of the volume of displacement has changed, however, and the C. B. must therefore have moved.

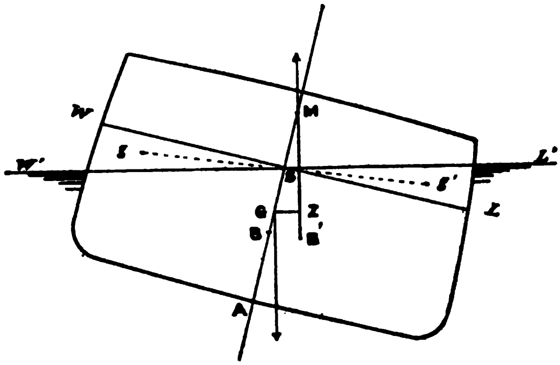


FIG. 19.

In the figure above, the section W. A. L. is considered to have been the immersed section when upright, with W. L. as the waterline in this position, and W^1AL^1 the section when inclined, with W^1L^1 the new waterline.

Therefore, the wedge-shaped volume W^1SW which has come out and is called the *emerged* wedge, must equal the similar volume L^1SL which has gone under the water and is called the *immersed* wedge.

For small angles, the Point S is on the center line of the waterplane; for larger angles this is not true and the consideration becomes more involved, and will not be treated of in this work.

Considering the ship inclined at a small angle:

The new volume of displacement W^1AL^1 has its C. B. at B^1. The location of this point might be calculated from the drawings, as was the location of B in the upright position, but, as will be seen below, may be more easily obtained.

B^1 being new center of buoyancy, the upward force acts through it, while the weight of ship acts down through the center of gravity, G.

Draw perpendicular to W^1L^1 (the plane of the surface of the water) through G and extend down, to represent downward action of weight.

Draw perpendicular to W^1L^1 (the plane of the surface of the water) through B^1 and extend up, to represent upward action of buoyancy.

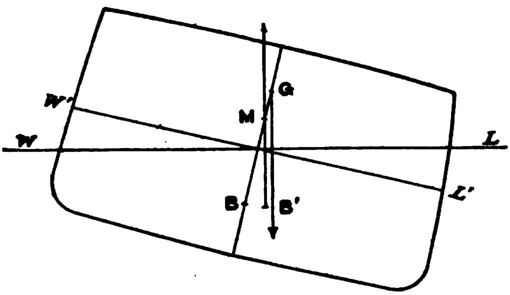


FIG. 20.

This from definition of metacenter will cut line BGS in point M, and we see that we have a couple.

Draw GZ from G perpendicular to vertical line through B^1.

$GZ =$ arm of couple.

Moment of couple $= W \times GZ$.

Where $W =$ weight of ship $=$ also force of buoyancy.

Inspection of figure will indicate that this couple is tending to return the ship to the upright position.

Now if the relative position of G and M was as in Fig. 20 above it is evident that the couple acting would tend to carry the ship farther away from the upright; and if G and M were coincident there would be no couple.

We therefore see that for a ship to float freely and be in stable equilibrium, the following conditions must exist:

(1) Weight of water displaced must equal total weight of ship.

(2) C. G. of ship must be in the same vertical plane as C. G. of displaced water, *i. e.,* center of buoyancy.

(3) C. G. must be below the metacenter.

It will be noted in the definition of metacenter in Chapter II the angle is defined as small. In ordinary ships, in practice, the point M does not change for inclinations up to 10° or 12°, but beyond this it moves.

The following general propositions as to *initial stability* may be stated:

If G is below M, the ship is in stable equilibrium.

If G is coincident with M, the ship is in neutral equilibrium.

If G is above M, the ship is in unstable equilibrium.

The term GM is called *metacentric height;* more properly the transverse metacentric height.

Assuming, as is the case up to 10° to 12°, that M remains fixed, $GZ = GM \sin \theta$,

$\therefore$ moment of couple is $W \times GM \sin \theta$.

If G is below M, this moment is tending to right the ship;

$\therefore W \times GM \sin \theta$ may be called the *moment of statical stability* at the angle θ, and this method is called the *metacentric* method of determining a vessel's stability.

The two things to be found are G and M.

We have seen how to find M.

The location of G depends solely on vertical distribution of weights on the ship, and its determination will be treated of later; it is a matter of long and laborious calculation when considered as a design problem. For ships actually existing it is easy of determination, as will be seen later.

Metacentric diagram.—We have seen how to calculate and plot CB and M. If to this combination we add the plotting of the location of G, we obtain the metacentric diagram. For a merchant ship, the position of G varies materially, due to different conditions of loading, and the range of drafts is also considerable. In warships these variations are not so wide, being due chiefly to con-

sumption of stores, fuel, and ammunition. The metacentric diagram is as shown in Fig. 21 following.

Inclining experiment.—The object of this experiment is to determine the vertical location of the C. G. It is generally performed when the vessel is approaching completion and weights may be determined accurately to check the results of design calculations.

In practice, the following points should be considered:

(1) Ship should have no free water in it, *i. e.*, all boilers, inner bottoms, tanks, &c., must be empty or entirely full.

(2) Ship should be moored head to wind and tide, and preferably where neither exist.

(3) No loose weights liable to shift should be allowed on board.

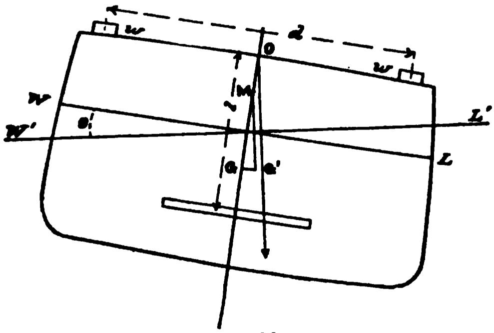


FIG. 22.

(4) Such crew as is on board at time of experiment should stay in center line and keep still.

Weights of known amount are shifted transversely across the deck and the distance of their C. G. from longitudinal center line of ship is carefully noted. The weight of ship itself can be determined from draft and displacement curves.

Considering Fig. 22,

let $W =$ whole weight of ship,

$w =$ inclining weight,

$G =$ center of gravity of original ship.

If the weight, w, be moved a distance, d, the C. G. of the whole weight, W, will move a distance, GG^1,

$$(1) \text{ or } GG^1 = \frac{w \times d}{W}.$$

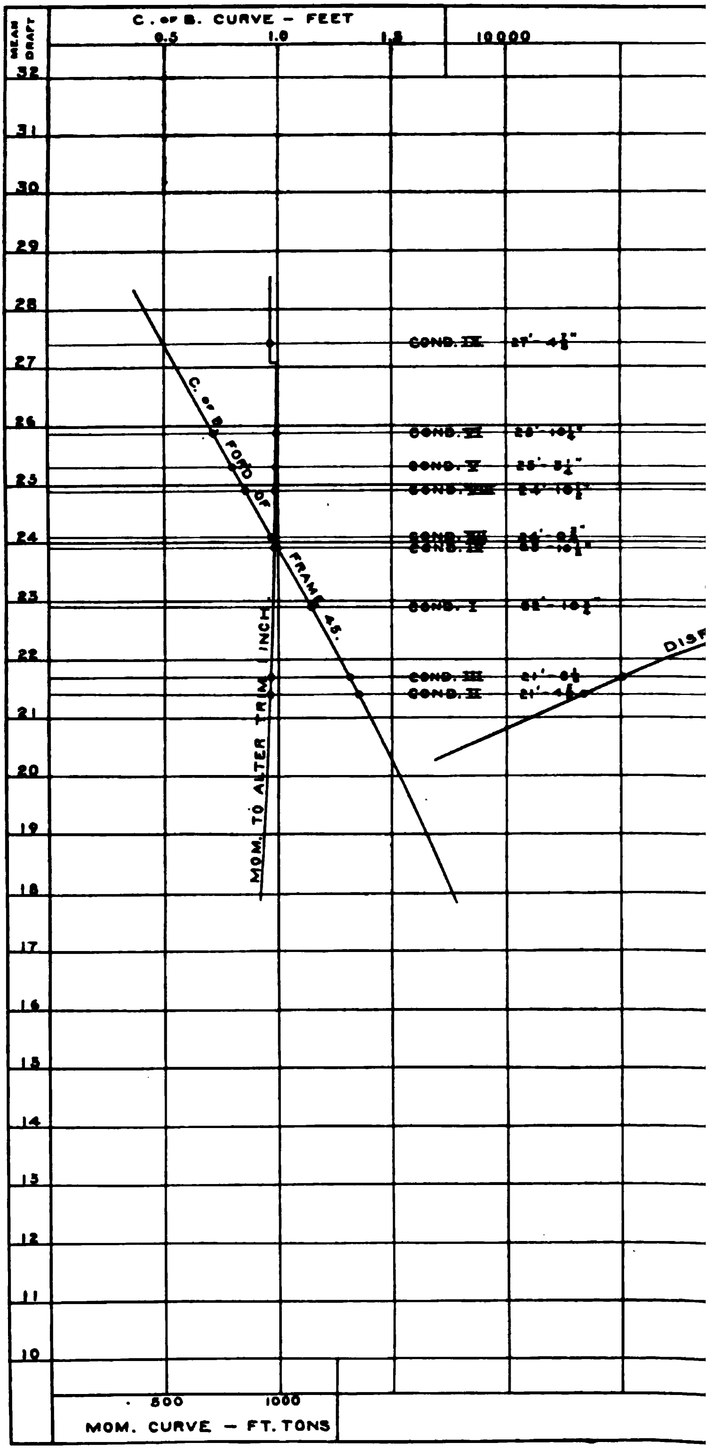
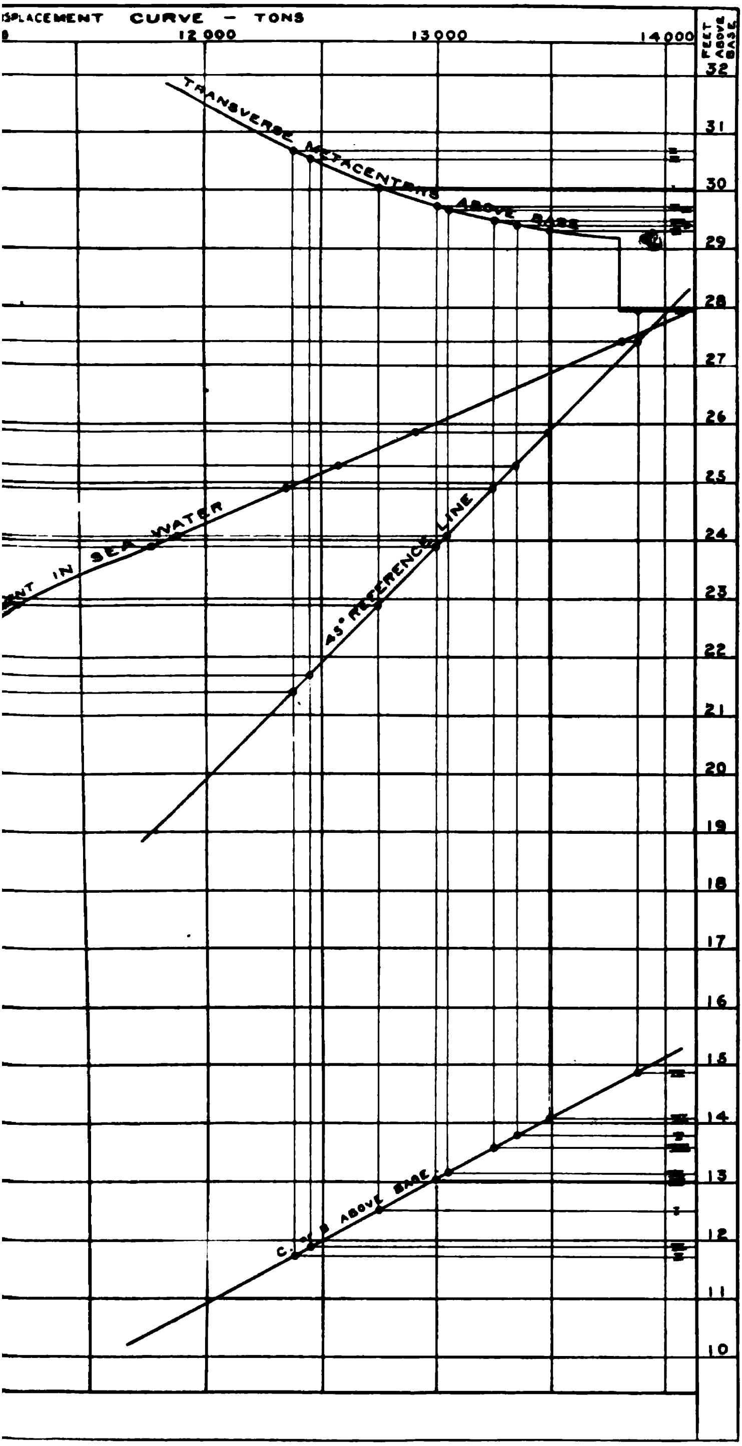


FIG. 21.—DISPLACEMENT AND OTHER



U. S. S. KEARSARGE AND KENTUCKY.

This the student has seen in his studies in mechanics.

Now, unless there are some external forces to prevent, the ship will incline, due to the movement of these weights, to an angle of, say θ°.

$$\text{From inspection, } \tan\theta = \frac{GG^1}{GM},$$

$$GM = GG^1 \cot\theta;$$

$$\text{or, from (1),} \qquad GM = \frac{w \times d}{W} \cot\theta.$$

The only term in this equation unknown is tan θ. In practice, it is usual to suspend a plumb bob from some point O down a hatch or turret opening and at some convenient point on a lower deck to erect a batten parallel to the W. L. in upright position. If this plumb line from point of suspension to batten in upright position has a length, l, and if, after inclination, the plumb bob has swung over on the batten a distance, a,

$$\tan\theta = \frac{a}{l} \text{ or } \cot\theta = \frac{l}{a},$$

$$\text{we can write } GM = \frac{w \times d \times l}{aW}.$$

Ordinary values for G. M. are:

Battleship	$3\frac{1}{2}$	ft.	to	$5\frac{1}{2}$	ft.
Monitor	9	"	"	14	"
Armored high-sided cruiser	3	"	"	5	"
Protected cruiser	$1\frac{1}{2}$	"	"	3	"
Gunboat	2	"	"	$2\frac{1}{2}$	"
Torpedo-boat destroyer	$1\frac{1}{2}$	"	"	$2\frac{1}{2}$	"
Sailing vessels, frigates	4	"	"	5	"

The value of G. M., as we have seen, may be found by calculating the location of M from the lines of the ship, and we may obtain the vertical location of G by calculation or by the inclining experiment.

For the vessel to be "stiff," that is, difficult to heel by external forces, the value of G. M. must be large. For steadiness in a seaway, the metacentric height must be small.

The value to be given G. M. is a point for the designer to settle, and depends on the type of ship and the qualities desired.

With a soft-ended ship where the ends are liable to be riddled in action and the waterplane destroyed, G. M. should be considerable, as also in sailing ships, to permit them to stand up under canvas.

For purposes of the gun platform it is desirable that G. M. be not too large, as a ship with a large G. M., when inclined, returns to the upright with a jerk.

As will be seen later in the discussion on stability, for a high-sided vessel it is possible for G. M. to be very small and still have a perfectly safe and stable ship, provided the waterplane is left intact. This is not an unusual condition in merchant ships, some of which even have a small initial negative G. M.

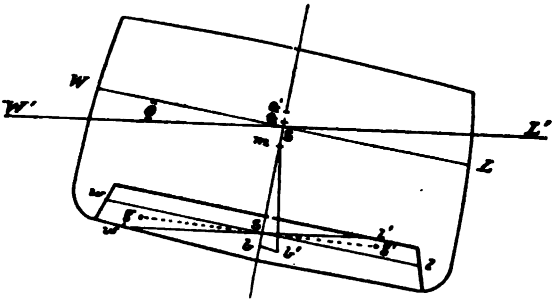


FIG. 23.

Effect on initial stability of free water in ship.—It will be noted in the inclining experiment that special attention was given to the necessity for having no free water.

Free water is water having a free surface.

It will be readily seen, on consideration, that if any boiler or compartment is completely filled with water, it will simply be a dead weight; but consider this sketch (Fig. 23).

If the ship be heeled to an angle, θ, the water in the tank will run over until its free surface is parallel to the new waterline.

As above,

$$\text{Wedge } wsw^1 = lsl^1 = v.$$

If their respective CG's be g and g^1, and b be the original CG of

water, we will find the CG of the whole amount of water moved to some point b^1 and if V_1 be whole volume of water in the tank $V_1 bb^1 = v \times gg^1$,

$$bb^1 = \frac{v}{V_1} \times gg^1,$$

and bb^1 is parallel to gg^1 from the principles of moments.

Now above we found that the moment of transference of the wedges WSW^1 and LSL^1 was equal to the volume of wedge $\times$ distance of transference of CG of wedge and was $I \times \theta$.

Because (see Fig. 19) $BB^1 \times V$ of whole ship $= gg^1 \times v$ wedge.

$BB^1 = BM \sin\theta$ or $= BM \times \theta$, as θ is a small angle,

$$BM = \frac{I}{V}$$

$$\therefore \frac{I}{V} \times V \times \theta = I \times \theta = gg^1 \times v \text{ of wedge.}$$

Similarly for the wedge wsw^1 and lsl^1 it is, as may be shown,

$$v \times gg^1 = i \times \theta.$$

i = moment of inertia of free surface of water about a fore-and-aft axis through S; θ = angle of inclination.

$$V_1 \times bb^1 = i \times \theta,$$

$$\therefore \quad bb^1 = \frac{i \times \theta}{V_1};$$

$$\text{or } bb^1 = bm \times \theta,$$

$$bm \times \theta = \frac{i \times \theta}{V_1}$$

$$bm = i/V_1.$$

Now the CG of the free water having moved to b^1, the weight acts in the line b^1m down through b^1, perpendicular to new water-line, and the effect on the ship is that of a weight whose CG is at m, which is called the virtual CG of the water.

We may illustrate by supposing a pendulum suspended at m, with its bob at b. If now the ship is inclined, the bob moves to b^1, the pendulum assuming the position mb^1. This is, in principle, identical with the case of the water.

The CG of the ship cannot now be assumed at G but has risen to a point G^1, and if $W_1 =$ the weight of water in tons $= \frac{V_1}{35}$.

Then if $W =$ whole weight of ship,

$$W \times GG^1 = W_1 \times bm,$$

$$= \frac{V_1}{35} \times bm,$$

$$GG^1 = \frac{V_1 \times bm}{35\,W} = \frac{V_1}{V} \times bm,$$

V being volume of whole displacement, W,

$$\text{but } bm = \frac{i}{V_1},$$

$$GG^1 = \frac{V_1}{V} \times \frac{i}{V_1} = \frac{i}{V}$$

The new moment of stability at angle θ is

$$W \times G^1M \times \sin\theta = W \times (GM - GG^1) \sin\theta$$

$$= W\left(GM - \frac{i}{V}\right) \sin\theta.$$

The metacentric height being reduced by $\frac{i}{V}$.

It is to be noted that the amount of water does not affect the result, but only the *moment of inertia of the free surface.* A small quantity of water having a large free surface will have a greater effect than a large quantity with a smaller free surface.

It is thus apparent why water having a free surface affects the determination of the location of CG by the inclining experiment, and also, in a general way, its effect on the initial stability.

We have shown above how to determine the location of the *longitudinal metacenter.* The general bearing that this point has on the conditions of equilibrium of a ship may be seen from considering sketch (Fig. 24):

For a given waterline, as WL, let B be center of buoyancy.

Draw BM perpendicular to this WL.

If trim be changed by small angle so that waterline is at W^1L^1, the volume of displacement remaining the same, the CB will move to B^1.

Draw B^1M perpendicular to new waterline through B^1 and the point M where BM and B^1M intersect, is the longitudinal metacenter.

For any condition of equilibrium we know that CG and CB must be in the same vertical line. So, given the length of a ship, we have

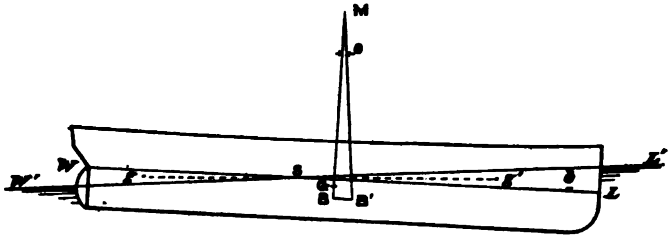


FIG. 24.

only to determine the longitudinal position of B to know the longitudinal position of G.

Change of trim due to longitudinal shifting of weights on board. —*Change of trim* = sum of *change of draft* forward and aft.

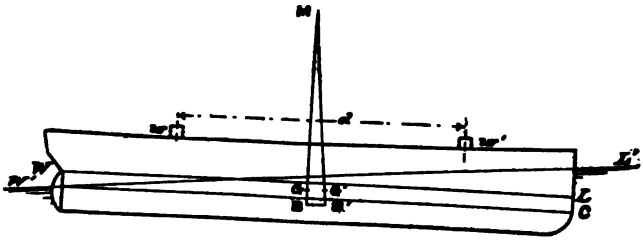


FIG. 25.

Consider Fig. 25.

Let w be weight on deck when ship floats at line, WL. If this is now moved forward a distance, d, to position w^1 the trim of the ship is changed. CG will move from G to G^1, GG^1 being parallel to line joining the original and final positions of w.

Let $W =$ displacement of ship,

$$GG^1 \times W = w \times d,$$

$$\therefore \quad GG^1 = \frac{w \times d}{W}.$$

CB will move from B to B^1, due to change in form of displacement.

Draw W^1C from W^1 parallel to WL and meeting forward perpendicular at C; then $CL = W^1W$ and change of trim is $WW^1 + LL^1 = CL^1$ say. The angle of inclination between W^1L^1 and WL is say θ and equals angle CW^1L^1.

$$\tan \theta = \frac{CL^1}{\text{length}} = \frac{x}{L}.$$

But we also have

$$\tan \theta = \frac{GG^1}{GM},$$

$$\therefore \frac{x}{L} = \frac{GG^1}{GM} = \frac{w \times d}{W \times GM} \text{ or}$$

$x = \dfrac{L \times w \times d}{W \times GM} =$ change of trim due to moving weight, w, through distance, d, feet.

In inches this is $\dfrac{12 \times w \times d \times L}{W \times GM}$.

Moment to change trim 1 inch is $w \times d = \dfrac{W \times GM}{12\,L}$.

To obtain this we must know $\begin{cases} \text{Vertical position of } G, \\ \text{Vertical position of } M, \\ \text{Displacement,} \\ \text{Length.} \end{cases}$

All of these are determined in making the design. As BG is small, a reasonable error in calculating vertical position of G makes little difference in the value of moment to change trim 1 inch. In ships of ordinary form, longitudinal BM approximates closely to length of ship, and to GM also; $\therefore$ *an approximation* to moment to change trim 1 inch is $\dfrac{W}{12}$.

This moment to change trim 1 inch is calculated to various WL's and in the U. S. Service a curve plotted.

Effect on trim of adding a weight of moderate amount.—If it be desired to place a weight on board so that the vessel will not

change trim, it must be placed so that its *CG* will be in the same vertical line as the *CB* of the added buoyancy.

If we assume a ship floating at a certain waterline and imagine her to sink down a small amount so that the new water-plane is parallel to the original water-plane, the additional buoyancy is formed of a parallel layer of nearly the shape of the original water-plane. The buoyancy, acting upward, of this parallel layer, will act through the *CG* of the layer, which will be very nearly over the *CG* of the original water-plane; therefore, to place a weight of moderate amount on a ship so that no change of trim occurs, we must place it vertically over *CG* of original water-plane. The distance the ship will sink = weight added ÷ tons per inch at this water-line.

We have assumed—

(1) That tons per inch do not change within the limits of change of draft.

(2) *CG* of parallel layer of added buoyancy is in the same vertical line as *CG* of original water-plane.

Both these are true for moderate amounts of sinkage and ordinary ship-shaped forms.

For larger changes in draft, it is not reasonable, as *CG* of water-planes changes from water-plane to water-plane.

As a rule, water-planes are fuller aft than forward, near the *LW* plane, and therefore the *CG* of water-planes would move aft as draft increases.

If now we wish to add a weight of moderate amount in some position forward or aft, we may consider—

(1) That it is added over *CG* of water-plane and calculate sinkage due to this.

(2) That it is then moved forward, and we may obtain change of trim by dividing, weight, multiplied by its distance from *CG* of water-plane, by moment to trim ship 1 inch.

To estimate the displacement of a vessel when floating out of designed trim.—If a ship floats parallel to her designed *LWL*, we can determine her displacement readily by the curve of displacement. If a weight already on board be shifted aft, the ship will change trim by the stern. The new *WL* will pass through *CG* of

original water-plane, and the displacement will be the same as at original waterline, no weight having been added.

Taking an actual ship in the water: If we measure draft aft and forward—

$$\frac{\text{Draft aft} + \text{draft forward}}{2} = \text{mean draft.}$$

On profile, draw the line parallel to designed WL at this mean draft line. The displacement will not be exactly correct measured to this line. wl in Fig. 26 represents the line parallel to designed WL at mean draft, and WL represents actual waterline.

If F be CG of water-plane, wl, draw W^1L^1 through F parallel to WL; then the actual displacement will be that up to W^1L^1 (which is nearly the same as that up to wl) + displacement of layer WLL^1W^1. Displacement up to wl may be found at once from displacement scale.

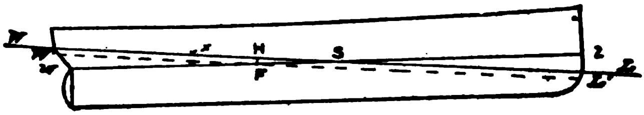


FIG. 26.

Let T = tons per inch at waterline wl, which is very nearly the same for WL and W^1L^1;

$SF = d$ inches, say = distance CG of water-plane wl is abaft middle of length.

The angle between wl and WL is such that

$$\tan\theta = \frac{wW + lL}{\text{length of ship}}$$

$$= \frac{\text{amount out of trim}}{\text{length of ship}}.$$

Let x = thickness of layer WLL^1W^1 in inches.

From triangle SFH

$$\tan\theta = \frac{x}{d} \text{ very nearly.}$$

$$\therefore x = d\tan\theta = d \times \frac{\text{amount out of trim}}{\text{length of ship}}$$

and xT = displacement of layer.

Whole displacement = displacement from curve by using mean draft + xT.

Effect of Adding Weights.—Such calculations may be utilized in the case of damage to the ship which admits water into a certain number of compartments. In such case of admission of water, three cases may be considered: *1st,* The compartments may be so situated that they are limited by a water-tight flat below the exterior waterline and the damage is such that the compartment is completely filled. In such a case, the water admitted acts just as so much dead weight, and the effects of it can be calculated in the manner indicated above. *2d,* The water may be admitted into a compartment where, while not in free communication with the exterior of the ship, it has a free surface. In such case it has a more serious effect on the stability than if it were a fixed weight, for, with a free surface, the water would move towards the inclined side, and, in addition to the upsetting arm which would be caused by the water considered fixed, there is an additional upsetting moment introduced by what *would be* the righting arm in a similar underwater body of a ship of the same shape, as has been explained apropos of the metacentric method. This additional upsetting arm must be added to the other upsetting arm already considered in the case of the fixed weight. *3d,* The compartment considered may be in free communication with the exterior water, and at the same time have a free surface. In this case, such a compartment may be considered as a part subtracted out of the ship at the waterline. Her load plane of flotation is seriously diminished in area, and, as a consequence, the metacenter is lowered and the righting arms diminished. In such a case, every inclination of the ship produces a new admission of water, so that if it is attempted to calculate the final position of equilibrium, it must be done by successive approximations.

It is needless to say that such calculations are extremely laborious. They have been made, however, in some cases, in which the ends of the ship are supposed to be riddled and fully thrown open to the sea. The whole middle part of the ship covered by armor is supposed to remain intact, thus reducing the vessel to a shape which can be considered as a new vessel altogether, with certain long

projections extending from the middle part and entirely underneath the water in the upright position.

Effect on trim of ship due to adding a weight of considerable amount.—The assumption made in previous investigations will not hold. In this case, allowance must be made for the following:

(1) Variation of tons per inch as the ship sinks deeper.

(2) Center of gravity of water-plane does not remain in same transverse section.

(3) Addition of large weight will alter location of CG of ship.

(4) Difference of form of immersed volume will alter position of CB and value of BM as area of water-plane, and therefore the moment of inertia, will change.

(5) Items (3) and (4) will alter value of moment to trim ship 1 inch.

For most cases, in practice, the following procedure will suffice:

(a) Assume weight so added that ship sinks parallel to original position.

(b) Find from curve of tons per inch the tons per inch at original load waterline.

(c) Divide added weight by this (b) to get first approximation to sinkage.

(d) Add the first approximation (c) to the original draft.

(e) Obtain tons per inch at the draft found from (d).

(f) Find mean of tons per inch from (b) and (e).

(g) Divide added weight by result of (f) for second approximation to sinkage.

(h) Add this amount (g) to original draft.

Now, one assumption made in (e) presupposes that the weight added be added over the CG of the layer of added displacement.

To approximate to this CG:

(i) Find CG water-plane at original draft.

(j) Find CG water-plane at draft (h).

(k) In profile connect (i) and (j), and bisect line.

Now, to find the alteration in position of CG of ship:

If $W =$ weight of ship,

$w =$ weight added,

$x =$ distance between CG of added weight and CG of ship,

(1) then change of CG is $\dfrac{w \times x}{w + W}$.

Now, referring to (4) above:

(m) Knowing new draft, the new vertical location of CB may be obtained from curve of center of buoyancy.

(n) Knowing new draft, the new value of BM may be obtained from displacement curve; and as we know new location of G,

(o) The value of longitudinal GM may be obtained.

(p) Using this and new displacement, we can obtain new value of moment to change trim 1 inch.

Now we may consider the weight shifted from the position, assumed above to give parallel sinkage, to the actual position and measure the distance.

(q) Weight added, multiplied by longitudinal shift will give moment to change trim.

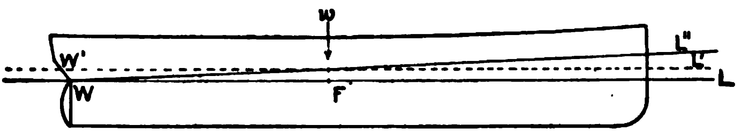


FIG. 27.

(r) (q) $\div$ (p) $=$ change of trim total.

This is to be divided up in the ratio of distance from bow to CG water-plane, and from stern to CG water-plane, to get the change forward and aft.

The above is to a certain extent an approximation but is generally sufficiently accurate.

To determine position of a weight on board a ship such that draft aft shall remain constant whether weight is on board or not.—This may be a special case, such as desiring to know how to locate a coal bunker or cargo space so that draft aft shall be the same whether coal or cargo is in the ship or not.

If we consider a ship floating at waterline WL as in Fig. 27, a

weight placed with its CG in the transverse section passing through the center of flotation will cause the vessel to sink to a waterline W^1L^1 very nearly parallel to WL.

What we wished, however, is not obtained, as the draft aft is too great by the distance WW^1.

We must now move the weight forward sufficiently to cause a change of trim of $WW^1 + LL^1$, which will bring the draft aft to its original amount and increase the draft forward by an amount equal to $WW^1 + LL^1$.

For example, we have a ship

(1) Length $= L = 200$ ft.

(2) Displacement (no coal on board) $= \Delta = 600$ tons.

(3) Center of flotation (CG of water-plane) in this condition from after perpendicular $= d = 100$ ft.

(4) Longitudinal BM (displacement as in (2)) $= BM = 650$ feet.

(5) Longitudinal GM (displacement as in (2)) $= GM = 645$ feet.

(6) Tons per inch (displacement as in (2)) $= x = 12$.

(7) Weight of coal or cargo to be added $= w = 60$.

(8) Moment to change trim $1'' =$

$$\frac{GM \times \Delta}{12\,L} = T \text{ or } \frac{645 \times 600}{12 \times 200} = 161.25 \text{ ft. tons.}$$

The parallel sinkage, supposing the coal placed with its CG in same transverse section as center of flotation, would be generally $= \frac{w}{x} =$ say k or for the particular example chosen $= \frac{60}{12} = 5''$.

Therefore we must shift the location of the coal forward by an amount such as to give a change of trim of $2k$, or, in case of example, $10''$ forward;

$\therefore$ a forward moment of $T \times 2k$, or, in example, $161.25 \times 10 = 1612.5$ ft. tons, and the distance forward of center of flotation is

$$\frac{T \times 2k}{w} \text{ ft., or } \frac{1612.5}{60} = 26.875 \text{ ft.}$$

Change of trim caused by a compartment being opened to the sea.—Consider a rectangular lighter 120 ft. long by 30 ft. broad, 12 ft. deep, floating at 4 ft. level draft in salt water, having an intact bulkhead 6 ft. from forward end. The compartment forward of this bulkhead is bilged below the waterline, find trim in damaged condition.

See Fig. 28, where *ABCD* is an elevation of the lighter floating at line *WL*, the bulkhead referred to being represented by *HGK*. Let us

(1) Find amount of mean sinkage due to loss of buoyancy.

(2) Find change of trim caused.

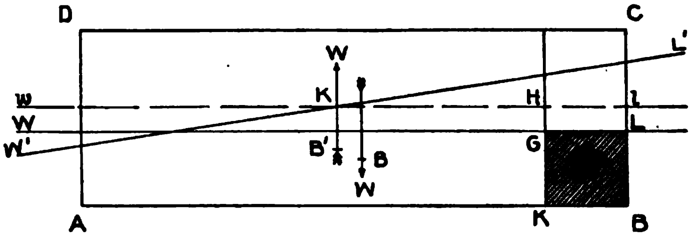


FIG. 28.

Consider (1) The lighter loses buoyancy represented by shaded part *GB* and, if we may consider that she sinks down parallel, will settle down to waterline *wl* such that volume $wG =$ volume *GB*. Let $x =$ distance between *WL* and *wl*,

$$\text{Volume } wG = wH \times 30 \times x.$$

$$\text{Volume } GB = GL \times 30 \times 4.$$

$$\therefore x = \frac{GL \times 30 \times 4}{wH \times 30}$$

$$= \frac{6 \times 30 \times 4}{114 \times 30} = \frac{12}{57} \text{ ft.} = 2\tfrac{1}{2} \text{ inches} +.$$

Consider (2) Volume of displacement $= 120 \times 30 \times 4$ cubic ft.

Weight $= \dfrac{120 \times 30 \times 4}{35} = \dfrac{2880}{7}$ tons acting down through *B* the center of gravity 60′ from either end.

By bilging we have lost buoyancy of part forward of bulkhead HK and center of buoyancy has shifted back to B^1 such a distance that B^1 is 57′ from after end $\left(\frac{120-6}{2}\right)$.

$\therefore$ W the weight of lighter acts down through B, and W the buoyancy acts up through B^1, giving a couple $=$

$$W \times 3 \text{ ft.} = \frac{2880}{7} \times 3 = \frac{8640}{7} \text{ ft. tons to trim ship forward.}$$

$$\text{Moment to change trim } 1'' = \frac{W \times GM}{12L}.$$

$GM = BM$ very nearly.

$$\therefore \text{Moment to change trim } 1'' = \frac{\frac{2880}{7}}{12 \times 120} \times BM = \frac{2}{7} BM.$$

$$BM = \frac{I_0}{V},$$

where $I_0 =$ moment inertia intact water-plane about a transverse axis through its center of gravity.

$V =$ volume of displacement in cubic feet.

$I_0 = \frac{1}{12}(114 \times 30) \times (114)^2$.

$V = 120 \times 30 \times 4 = 14400$.

$$\therefore BM = \frac{30 \times (114)^3}{12 \times 14400}.$$

$$\text{Moment to change trim } 1'' = \frac{2 \times 30 \times (114)^3}{7 \times 12 \times 14400} = 77.6 \text{ ft. tons.}$$

$$\therefore \text{Change trim} = \frac{8640}{7} \div 77.6 = 15.9''.$$

The new waterline W^1L^1 will pass through CG of waterline wl at K, and change of trim aft and forward will be as 57 : 63, or

$$\text{decrease draft aft} = \frac{57}{120} \times 15.9 = 7\tfrac{1}{2}'' \text{ nearly,}$$

$$\text{increase draft forward} = \frac{63}{120} \times 15.9 = 8.4'' \text{ nearly};$$

$$\therefore \text{new draft aft} \qquad = 4' + 2\tfrac{1}{2}'' - 7\tfrac{1}{2}'' = 3'\ 7'',$$

$$\text{new draft forward} = 4' + 2\tfrac{1}{2}'' + 8.4'' = 4'\ 10.9''.$$

The same result would be obtained by considering weight of water in compartment GB as acting downward and taking its moment about center of flotation K of the intact portion of waterline wl.

NOTE.—It has been assumed that moment to change trim for waterline wl remains constant as vessel trims. This is not absolutely so but may be allowed for if desired by taking mean between moment to change trim for waterlines wl and W^1L^1 and using this mean in determining change of trim.

Problems.

Transverse metacenter.

(43) A box-shaped lighter is 100 feet long, 28 feet broad, and displaces 360 tons in salt water. Find the height to transverse metacenter above the bottom of the keel when the vessel floats on an even keel.

(44) A cylindrical vessel 100 feet long and 15 feet in diameter floats with its axis at the waterline. Find the height of the transverse metacenter above the center of buoyancy.

(45) The half ordinates of the load water-plane of a vessel are 6 feet apart, and their lengths are 0.3, 2.3, 4.5, 6.4, 7.7, 8.6, 9.0, 9.2, 9.3, 9.1, 8.8, 8.4, 7.6, 6.2, and 3.5 feet, respectively. The displacement to this waterline is 156 tons in salt water. Find the height of transverse metacenter above the center of buoyancy.

(46) A box-shaped vessel 120 feet long, 25 feet broad, and 15 feet deep, floats at a draft of 10 feet. Find the distance of the longitudinal metacenter above the center of buoyancy.

(47) The moment of inertia of a water-plane of 22,500 square feet about an axis 20 feet forward of the center of flotation, is found to be 254,000,000 in foot-units. The displacement of the vessel being 14,000 tons, find the longitudinal B. M.

(48) The semi-ordinates of the load water-plane of a vessel, 30 feet apart, are, commencing from forward, 0.1, 5.3, 10.8, 15.0, 17.6,

18.5, 18.4, 17.5, 15.3, 10.8, and 3.8 feet, respectively. The displacement is 2210 tons. Calculate the distance of the longitudinal metacenter above the center of buoyancy.

(49) A ship displacing 9972 tons is inclined by moving 38 tons 52 feet across the deck, and a mean deviation of $8\frac{1}{8}$ inches is obtained by pendulums 15 feet long. What is the G. M.?

(50) What weight is required to be moved 50 feet across the deck of a ship of 8500 tons displacement to incline her 6 degrees when she has a metacentric height of 4 feet?

(51) A vessel is heeled by moving a known weight a certain distance across the deck; what is the expression for the metacentric height of the vessel in terms of the weight moved, the distance moved through, the displacement of the vessel, and the angle of heel? Prove the formula. What will be the angle of heel if a weight of 30 tons is moved 45 feet across the deck of a vessel of 5500 tons, the G. M. being 3.25 feet?

(52) A vessel 300 feet long and 2100 tons displacement has a longitudinal metacentric height of 480 feet. Find the moment to change trim 1 inch.

(53) A water-plane has an area of 13,200 square feet, and its moment of inertia about a transverse axis 14 feet forward of its center of gravity works out to 79,639,726 in foot-units. The vessel is 350 feet long, and has a displacement to the above waterline of 5625 tons. Determine the moment to change trim 1 inch, the center of gravity being 7 feet 6 inches above the center of buoyancy.

(54) Find the moment to change trim 1 inch of a vessel 420 feet long, having given the following particulars: Longitudinal metacenter above center of buoyancy, 452 feet; center of gravity above center of buoyancy, 10 feet; displacement, 14,300 tons.

(55) A vessel 310 feet long and 2350 tons displacement has a longitudinal metacentric height of 385 feet. Find the change of trim caused by moving a weight of 6 tons already on board through a distance of 175 feet from forward to aft.

(56) A vessel floats on an even keel at 15 feet draft. She is 280 feet long and displaces 3100 tons, and the longitudinal metacentric height is 326 feet. How far must a weight of 40 tons on deck be moved to make her draw 16 feet aft?

(57) A ship of 16,000 tons displacement and 450 feet in length has a moment to alter trim of 1650 foot-tons, and trims 4 inches by the head. How will she trim after transferring 50 tons of ammunition from the forward to the after magazine, the distance being 240 feet?

(58) A vessel is floating at a draft of 12 feet 6 inches forward, and 14 feet 3 inches aft. The tons per inch is 20; length, 300 feet; center of flotation, 12 feet abaft the middle of length; moment to change trim 1 inch, 320 foot-tons. A weight of 30 tons is placed 30 feet from the forward end of the ship. What will be the new drafts of water?

(59) A vessel 360 feet long trims 6 inches by the stern at a mean draft of 18 feet. The tons per inch at this draft is 24; center of flotation, 15 feet abaft the half length; moment to change trim 1 inch, 450 foot-tons. What weight placed 45 feet from the stem will bring her to even keel, and what will be the new draft?

(60) A ship is floating at a draft of 21 feet forward and 22 feet 6 inches aft, just before the following weights are placed on board:

Weight	Distance from C. G. of Water-plane
25 tons	60 feet forward.
15 "	80 " "
30 "	30 " "

What will be the new draft forward and aft, the moment to change trim being 800 foot-tons, tons per inch 35, and center of flotation at the half length?

CHAPTER VI.

STABILITY AT LARGE ANGLES OF INCLINATION.

Up to this point all the problems which we have considered have been treated by what is called the *metacentric method*. This presupposes that, for the limits within which the inclinations take place from any cause, the verticals through the different centers of buoyancy all practically meet at the same point, called the metacenter, which was defined. It was pointed out at the time that for ordinary ships this method was only applicable for transverse inclinations up to 10 or 12 degrees. It may now be mentioned that it is only applicable to longitudinal inclinations very much smaller in angular measure, but is practically sufficiently accurate, in most cases, within a range of a change of trim from 5 to 10 feet from the normal.

A general investigation of the stability at large inclinations necessitates methods more accurate and of more extended application; in other words, such as can be applied to all angles of heel. For such purposes it is necessary to calculate the actual righting arm for any inclination corresponding to any given displacement. Numerous methods have been proposed and a number are actually in use for making these calculations. Most of them are derived from what is known as Atwood's Formula.

Statical Stability at Large Angles of Inclination.

Atwood's Formula.—In the preceding chapters we have dealt only with the initial stability or stability at small angles of inclination.

In actual service this is not sufficient, as the ship is bound to be inclined beyond the 10 or 12 degrees to which this method is applicable.

Consider Fig. 29, representing the cross-section of a ship inclined to an angle θ.

WL represents original waterline.

B represents original CB.

W^1L^1 represents waterline in inclined position.

W^1L^1 intersects WL in point S, and, as stated above, as this is a large angle, it will not be in center of ship.

Volume WSW^1 is, as before, the emerged wedge.

Volume LSL^1 is, as before, the immersed wedge.

g and g^1 are respective positions of the centers of gravity of these wedges.

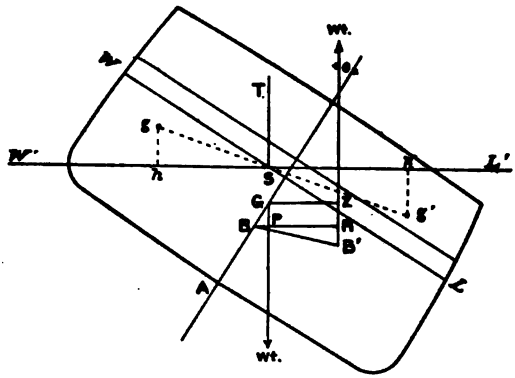


FIG. 29.

The volume of displacement has not changed; therefore, volumes of these wedges are equal.

Let $v =$ volume of wedge.

The center of buoyancy of vessel, when inclined, is B^1. The upward support of buoyancy acts through B^1. The downward force of weight acts through G, the center of gravity of ship.

Draw GZ and BR perpendicular to the vertical through B^1. Draw gh and g^1h^1 perpendicular to new waterline W^1L^1.

(1) The moment of the couple tending to right the ship is

$W \times GZ$, or, as we term it, the *moment of statical stability* where $W =$ displacement of ship.

$$GZ = BR - BP,$$
$$= BR - BG \sin \theta.$$

(2) $\therefore W \times GZ = W \,(BR - BG \sin \theta)$.

By examination it will be seen that all the terms of the above are known, except BR. We may obtain this as follows:

The new volume W^1AL^1 is obtained from the original volume WAL by shifting the volume, v, through a horizontal distance hh^1.

$\therefore$ the horizontal shift of center of buoyancy is $BR = \dfrac{v \times hh^1}{V}$

where $V =$ original volume of displacement $= W \times 35$.

$\therefore$ the moment of statical stability from (2) is

$$W\left(\frac{v \times hh_1}{V} - BG \sin \theta\right) \text{ foot tons.}$$

This is known as Atwood's Formula.

(3) The righting arm or lever GZ is $= \dfrac{v \times hh^1}{V} - BG \sin \theta$.

If, therefore, we wish to know the length of the righting arm at any angle of inclination, we must know—

(1) Location of CB in upright position.

(2) Location of CG of ship.

(3) Volume of displacement, V.

(4) Value of moment of transference of wedges parallel to the new waterline, *i. e.*, $v \times hh^1$.

The determination of (4) involves a considerable amount of calculation and will be explained later.

Supposing, however, that we are able to obtain them, we wish to plot a *curve of statical stability*.

The lengths of GZ vary as the angle of heel varies. Usually GZ increases gradually to a maximum, then decreases to zero, and then becomes negative, indicating that beyond this angle, the couple $W \times GZ$ becomes an upsetting couple instead of a righting couple.

The early method of calculating the righting arm for a given displacement is known as Barnes' Method. For every 10 degrees

of inclination, the volumes of the wedges, v, are calculated, and also their centers of volume, g_1 and g_2. (See Fig. 30.)

Certain corrections are made in the calculations, owing to the fact that the point, S, is not, in general, on the middle line. Into the details of this calculation it is not necessary to enter.

The result finally obtained is a series of values of the arm BR from o inclination up to any inclination desired; usually carried up to 90 degrees. From each of the ordinates thus obtained is deducted the quantity $BG \sin \theta$; BG being the distance of the actual center of gravity above the center of buoyancy. This quantity, it will be observed, when plotted, gives a curve of the form of a sinus-

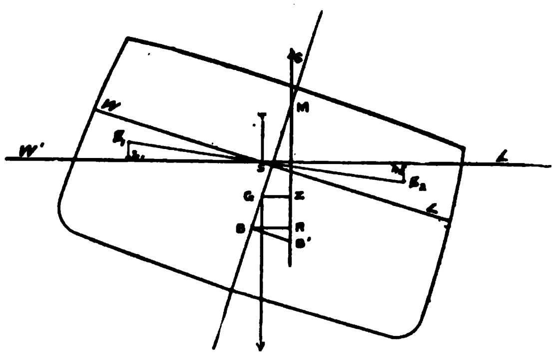


FIG. 30.

oid, and, as the center of gravity is, in almost all ships (except racing yachts with heavy lead keels and submarine boats) above the center of buoyancy, this term will be always subtractive. The resultant values will be the righting arms GZ.

Let us suppose that the position, G, the center of gravity for a given displacement of the ship, is determined. We can construct a curve with the actual righting arm GZ for each inclination, and we will then have a curve of the shape referred to. It will be observed (see Fig. 33) that the curve starts with a value of the righting arm, o, at the upright, which rapidly increases and finally reaches a maximum; thence decreasing until it finally crosses the axis, again becoming o. It is at the angle indicated by this maximum point that the vessel has her greatest righting moment and resists with the greatest power a force tending to upset her. At the point where the curve crosses the axis, the stability vanishes. In other words, the ship will, without any force tending to upset her, go farther and farther away from the upright and tend to

"turn turtle." This limiting angle is called the *range of stability* for the given conditions of displacement and position of center of gravity.

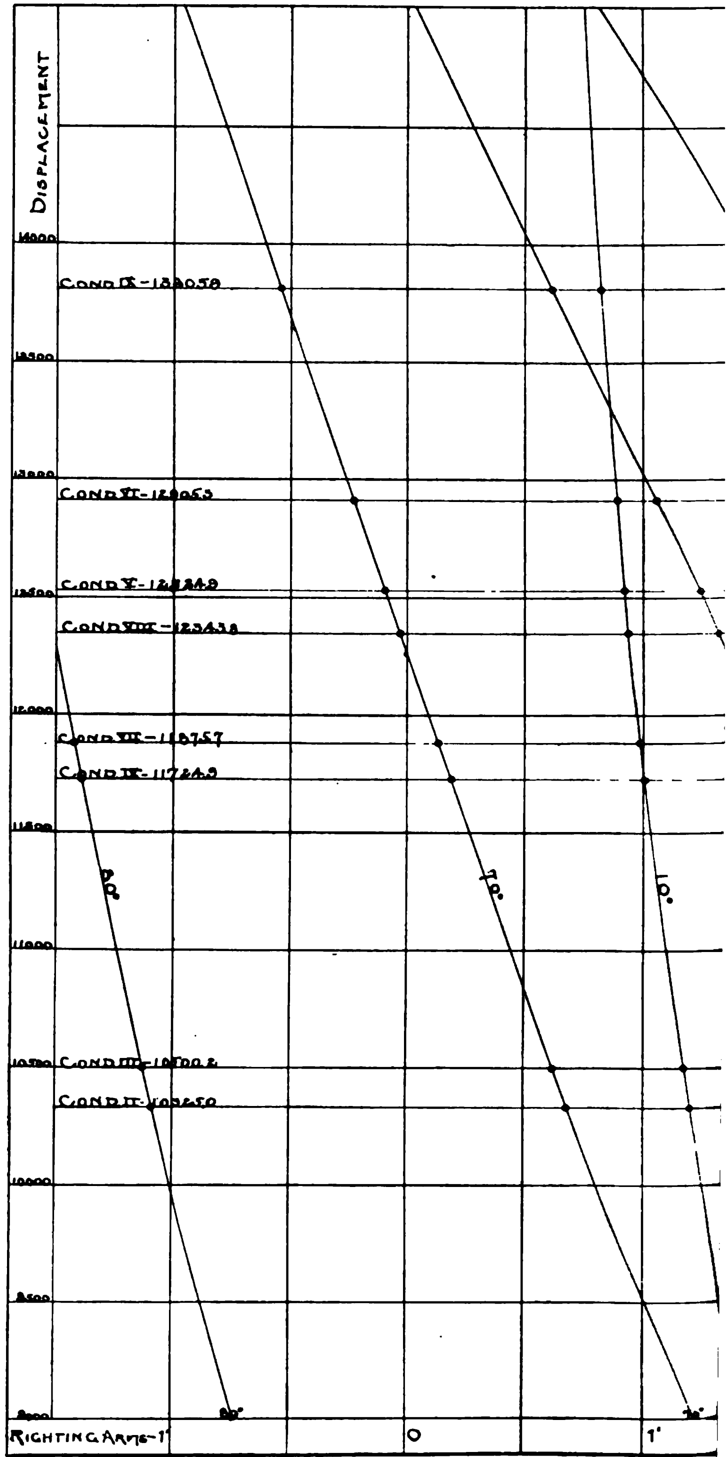
The method of calculation proposed by Barnes is conveniently applicable only to the investigation of the stability of a ship at a single given displacement. We know that ships are constantly varying in their displacement within wide ranges, and other methods of calculation have been adopted by which, with a series of curves, the curve of statical stability can be gotten out for any given displacement. There are a large number of such methods, which can be found in the standard text-books. The method used in the U. S. Service is not given here as it is of considerable length, but may be found if desired in the "Instruction for Standard Ship Calculations," referred to before.

All these methods depend upon a choice of a position on the center line, which is considered temporarily as the position of the center of gravity for all displacements and axis for all inclinations. With this pole or axis and a fixed inclination of ship, the righting arms, or righting moments are obtained for a series of displacements. These righting arms, or righting moments, plotted as ordinates with the corresponding displacements as abscissæ, give the curve for this inclination. Similar curves for a series of inclinations are plotted on the same diagram, forming what is known as the *cross curves of stability, i. e.,* curves of righting arms for a given angle of inclination for varying displacements. There are shown in Fig. 31, the cross curves of stability of the *Kearsarge.* The axis is taken at 24 feet above the bottom of keel or base.

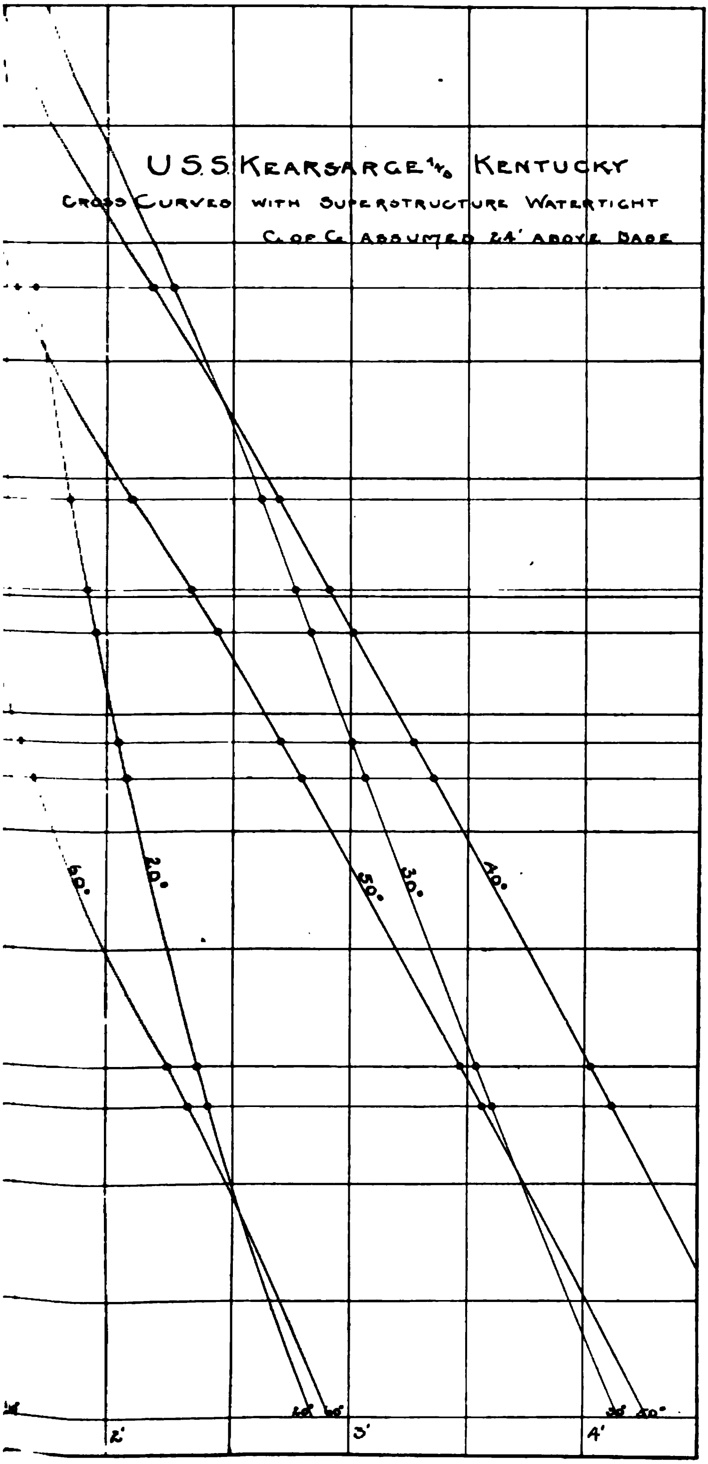
There will be noted a series of curves marked 10 degrees, 30 degrees, 40 degrees, etc. These curves are the cross curves just referred to.

The relation between the cross curves and the ordinary curves of stability will be seen from Fig. 32. There are shown, in this figure, four curves of stability for a vessel at displacements of 2000, 2500, 3000 and 3500 tons. These are placed as in perspective and through the ordinates at any given angle we can draw a curve which will be the cross curve of stability at that angle.

Suppose it is desired to know, with the cross curves, the curve of statical stability for any given displacement, say for a condition with the ship complete with armament, ammunition, water in tanks, and machinery, and normal coal, corresponding to a displacement of 11,725 tons. Take on the cross curves (Fig. 31) a line (indicated as Cond. IV—11,725 tons), and corresponding to each inclination, we note the intersection of the corresponding cross curves. If now there be laid off on an axis, to suitable scale, these angles of inclination, and ordinates be erected which equal the distance from the



DISPLACEMENT
14000
13000
12000
11000
10000
70°
10°
80°
RIGHTING ARMS-1'
0
1'


U.S.S. Kearsarge & Kentucky
Cross Curves with Superstructure Watertight
C. of G. assumed 24' above base
60°
20°
50°
30°
40°
2'
3'
4'

line, o, to the respective curve intersections, multiplied by the weight of ship, we would obtain a curve of statical righting moment for a position of the center of gravity 24 feet above the base, that being the assumed position of the axis for our cross curves; this has then only to be corrected, by taking the distance of the actual center of gravity from the axis and multiplying it by the displacement and by the sine of the angle of inclination, adding it to the righting moment obtained from the cross curves if G is below the axis, and subtracting it from the righting moment if G is above the axis.

There will thus be obtained a curve of righting moments for the actual position of G, and we have only to divide the righting mo-

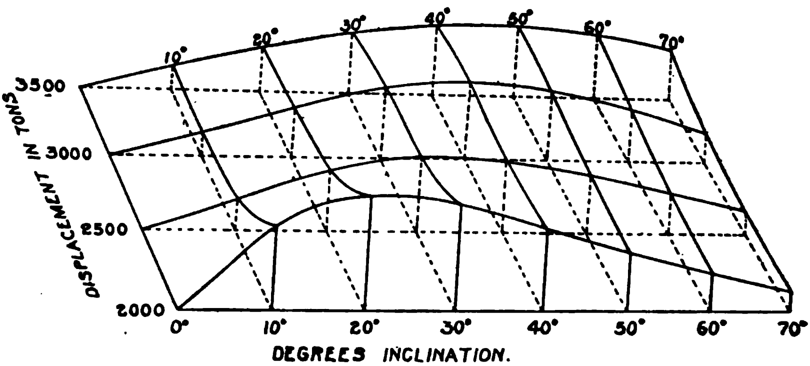


FIG. 32.

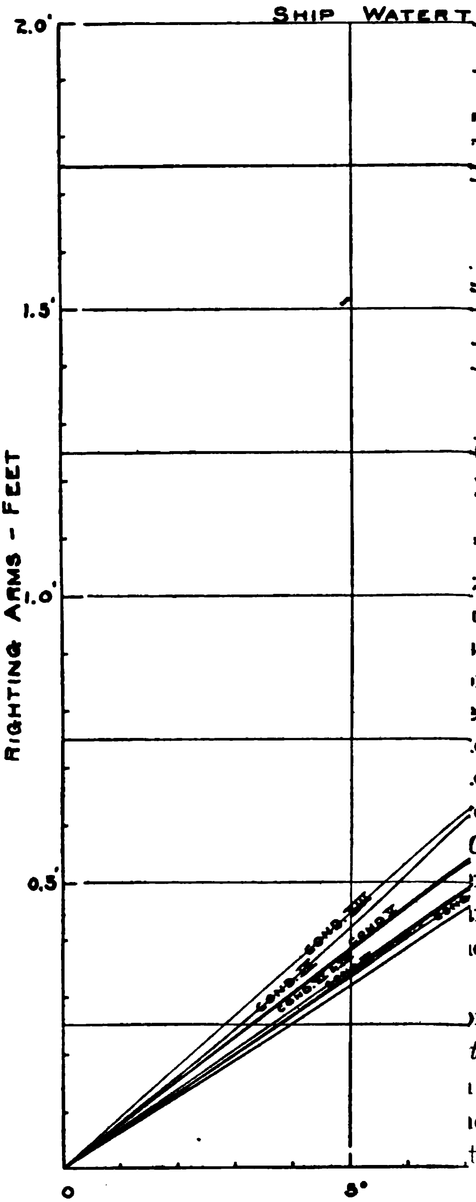
ments by the displacement to obtain the righting arms. In other words, the same curve of the statical stability, read with a suitable scale, may be considered either as the curve of righting moments or the curve of righting arms. The determination of a statical stability curve from the cross curves is equivalent to mechanical interpolation.

In the case of the *Kearsarge,* the actual center of gravity for the condition just considered is 1.44 feet above the axis, so that we would have to make a correction, subtractive from the moment obtained by the diagram, of 11,725 $\times$ 1.44 $\times$ the sine of the angle.

It is evident that, for any other condition of displacement and position of center of gravity, by the use of these same cross curves of stability and in a precisely similar manner, a new curve of statical stability for the given set of conditions may be obtained.

There are shown in Fig. 33, drawn to a large scale, such a series of curves of statical stability for the U. S. S. *Kearsarge,* under eight different conditions:

Condition No. IV is that for which the method of obtaining the curve has been explained in detail.



SHIP WATER T
RIGHTING ARMS - FEET
2.0'
1.5'
1.0'
0.5'
0
5°

It may be remarked concerning these curves that the position of the maximum righting lever is, in all cases, nearly 30 degrees, and that the range of stability varies from 46.2° to 53°. A consideration of these curves, or of any similar curves of statical stability, will at once show why the metacentric method is limited to small inclinations in its application. It has been stated that, in the application of this method, the fixed point called the metacenter was that at which the verticals through the center of buoyancy for each inclination all met. As a matter of fact, at comparatively small inclinations, this is not even practically so.

Considering the actual condition of the *Kearsarge* when the inclining experiment to determine the position of her center of gravity was made, we find that the ship then displaced 11.099 tons. The actual degree of inclination obtained, from which the center of gravity was calculated, was about $2\frac{3}{4}$°. For such an inclination, the intersections of the verticals through the centers of buoyancy are very accurately at the metacenter.

When, however, the ship is inclined over to an angle of 30°, the vertical through the new center of buoyancy no longer intersects the center line at the point, M, but is appreciably below it, and the righting arm, GZ, for this inclination of 30° is materially less than it would have been if the vertical through the center of buoyancy, B_1, passed through the metacenter, M. It may be remarked that the righting arm for a given inclination by the metacentric method was $MG \sin \theta$. If this method were applicable to all inclinations, the curve of statical stability would be a curve of sines, and the maximum righting arm would be equal to MG at 90° of inclination (in other words, when the ship is on her beam ends), and the range of stability would be 180°. How far this is from the truth is seen at once on an inspection of the actual curves of statical stability of the *Kearsarge*.

The principal influences determining the forms and range of the curves of statical stability in a ship may be stated as, *1st*, freeboard, including in this the reserve of buoyancy; *2d*, the beam; *3d*, the vertical position of the center of gravity, and, *4th*, the vertical position of the center of buoyancy when the ship is upright.

The freeboard and beam are of course relative, and are to be considered with relation to the draft of water. The vertical position of the center of gravity is to be considered with reference to the total depth of the ship, and the center of buoyancy with reference particularly to the mean draft.

A high freeboard conduces to a great range of stability. The maximum righting arm is generally obtained shortly after the deck edge is immersed. In the case of the *Kearsarge,* with a mean draft of 23 ft. 10½ in., this immersion occurs at an angle of about 18°. If it be noted that the maximum righting lever of the *Kearsarge* occurs at an angle of about 28 degrees, it will be seen how great an importance the immersion of the deck edge has upon the stability. An inspection of Figs. 29 and 30 will also show why this is, for the points g_1 and g_2, which have been spreading farther and farther as the wedge grows larger, will come in towards the center again, and the distance h_1h_2 will diminish rapidly. At the same time the deduction from the righting arm, due to the position of the center of gravity above the center of buoyancy, will become greater and greater.

Thus is seen the importance of freeboard and the reserve of buoyancy.

The reserve of buoyancy means the volume and corresponding available buoyancy of the part of the ship not immersed, but which may be made watertight. In most vessels this enclosed part is limited by the main deck, although in some vessels there are additional watertight enclosures above that deck which are to be taken into account. It is evident that, if this part of the ship is watertight, additional weight could be placed on the ship equal to this reserve of buoyancy before she would sink beneath the water. The sum of displacement and the reserve of buoyancy is thus the total floating power of the ship considered as a watertight shell.

If then, the center of gravity remains approximately in the same position relatively to the base, with a high-freeboard vessel as with a low-freeboard vessel, the deck edge will go under only at a much greater inclination, and the angle of maximum righting lever will be correspondingly increased. It may be added that a similar extension occurs of the total range of stability. It is for this reason that high-freeboard cruisers, and passenger vessels of the merchant mar-

ine, need, and are usually given, less initial stability than vessels of low freeboard.

The influence of the beam is largely on the initial stability for reasons that have been explained in the earlier part of this work, and this influence will continue very predominant until somewhat after the deck edge has been immersed. The metacentric height will be increased, and the relative deduction for the height of the center of gravity over the center of buoyancy will not be so great. The effect of the great beam will, however, be greatly diminished as the angles of inclination grow larger and the total range of stability is, in general, comparatively little increased.

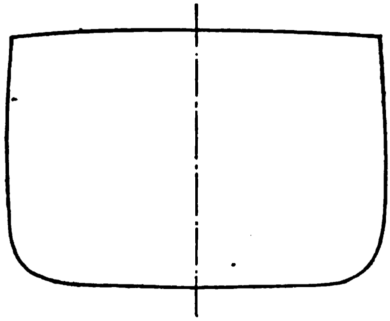


FIG. 34.

As to the effect of the vertical position of the center of gravity, it is clear that raising the center of gravity of the ship one foot, for instance, will decrease the righting arms by one multiplied by the sine of the angle of inclination, and, by just such an amount, would reduce the maximum righting arm and reduce correspondingly the range of stability. It will also be seen that the effect of adding water-ballast, which, as has been stated, almost invariably lowers the center of gravity, will usually produce an increase in the maximum arm and in the range of stability; providing, that, as must be carefully looked into, the water-ballast tanks are completely full.

The effect of a full under-water section, as in Fig. 34, is to lower the center of buoyancy. As the location of the metacenter is deter-

mined by measuring up from the center of buoyancy, this has the effect of lowering the metacenter with reference to the base. The center of gravity of the ship will also be lowered, but usually not to the same extent as the metacenter. The net result then may be considered to be that in the ships with a V-shaped section (Fig. 35), where the center of buoyancy is higher, the initial stability and the maximum righting arms will be increased, but the range of stability will be less affected and may be decreased. It is partly for this reason that sailing vessels and yachts are usually given a much sharper dead rise than steamers.

The influence of these different conditions will be evident on examining the curves of stability of the *Kearsarge*. Here is a ship

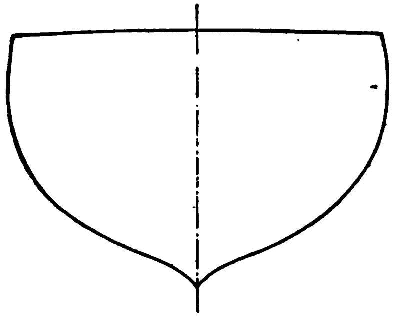
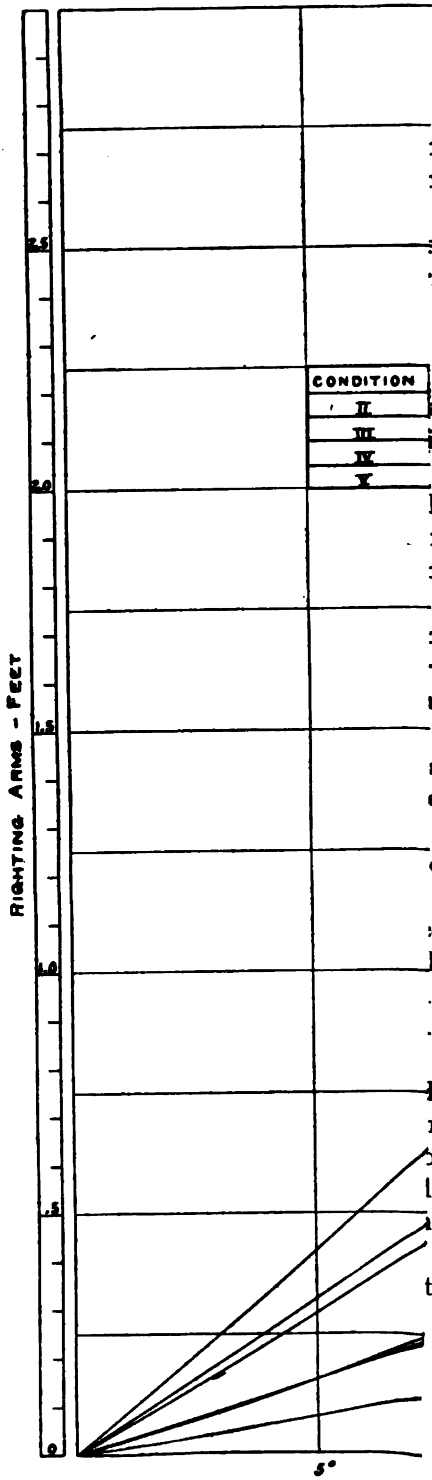


FIG. 35.

of comparatively low freeboard in which the center of gravity of the ship is high, owing to the weight of the guns and armor placed high up in the vessel. The beam is great. Under these circumstances, all the curves show a good initial stability, but the maximum righting lever occurs at an angle of about 30° and the range of stability varies from 46.2° to 53°.

Let us compare with this ship the stability curves of the *Alabama* (see Fig. 36). The general arrangement of weights in the two ships is somewhat similar, but, owing to the condition of a deck forward and the consequent raising of the forward turret, the center of gravity is raised slightly higher above the base in most conditions. The important point of difference in the hull design is, however, that the *Alabama* has, in lieu of a comparatively small



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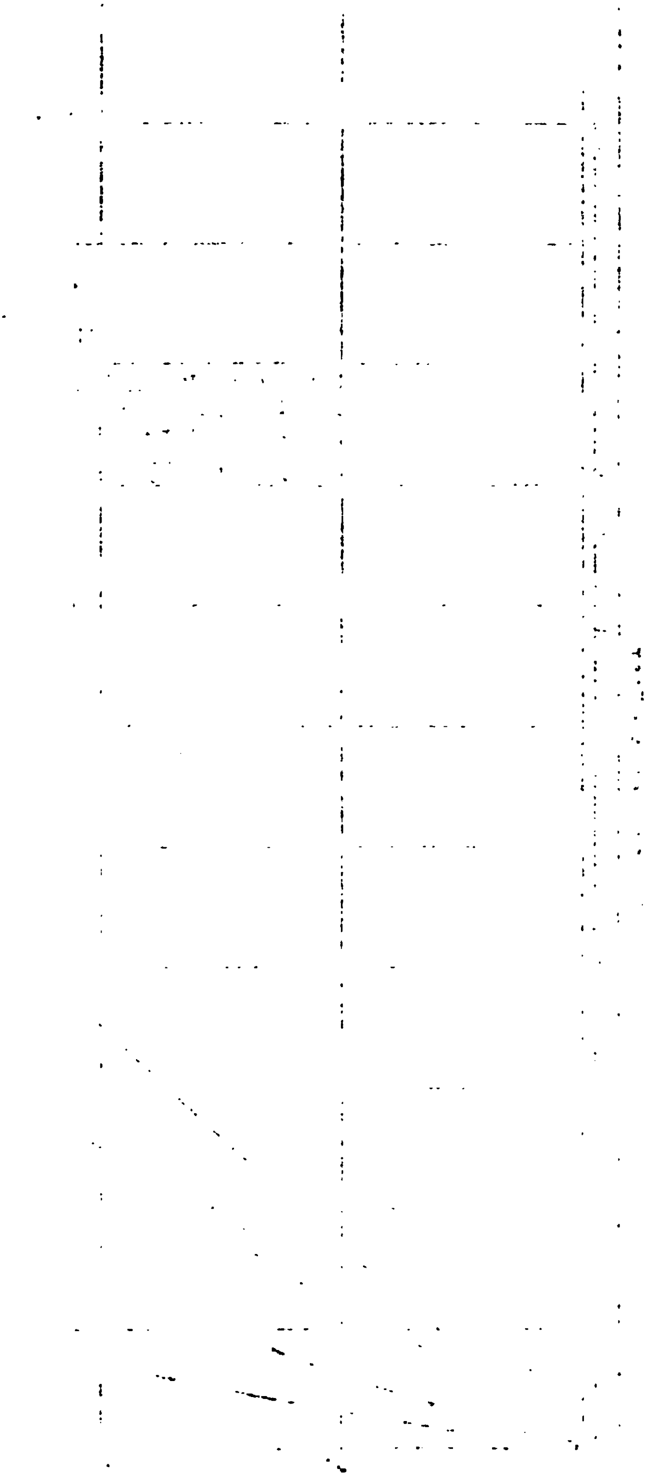


superstructure, an upper deck extending from the stem two-thirds of the way to the stern. It will be observed how the greater freeboard and reserve of buoyancy increase the range of stability. The increase would be greater but for the effect of the rise of the center of gravity. It will be observed that the maximum righting arm is at an angle of about 8° greater than for the *Kearsarge,* and that there is a similar increase in the maximum range of stability.

In comparison with these ships, examine the curves of the *Raleigh* (Fig. 36), a vessel with comparatively small metacentric height, position of the center of gravity medium but rather higher than in most cruisers of a similar character, and fairly high freeboard. Here the maximum righting arm occurs at an angle in the neighborhood of 40°, and the range of stability varies from 60° to 71°. Here it is seen that, notwithstanding the very much smaller metacentric height of the *Raleigh,* and her much less ratio of beam to depth, her freeboard gives her the advantage of the *Kearsarge* in the position of maximum righting lever and in the range of her stability. But note the difference on the *Raleigh* of the smaller initial stability (that is to say the comparatively high position of the center of gravity), which gives her less range of stability than is the case with a great number of cruisers.

There are, in Figs. 37, 38, and 39 a series of the curves of statical stability of a number of our ships:

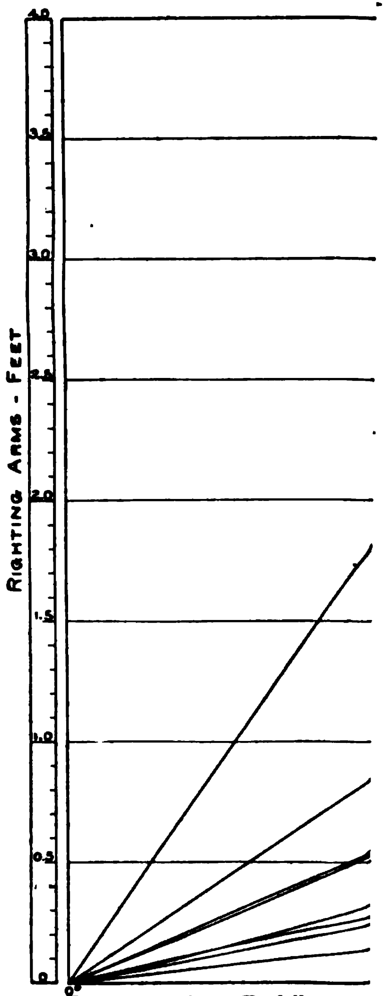
The first of these figures (37) is for vessels in the light condition, without provisions, stores, coal, or ammunition, boilers being at the steaming level; the second (38), for vessels in normal condition, with normal supplies of feed water, stores, ammunition, and coal (the lower bunkers full); the third (39), for vessels in full-load condition, with full allowance of stores, feed water, and ammunition, and with bunkers full. The great contrast between the different kinds of ships will be seen at once. No. 1, the curve of the *Arkansas,* now *Ozark,* a monitor, has a very great initial stability and a great righting arm, but a few degrees of inclination puts the deck edge under, and her stability decreases with great rapidity, vanishing at a comparatively small angle. Protected

cruisers and gunboats, with very high freeboards and with fair metacentric heights, like the *Chattanooga* and *Dubuque,* have a range of stability approximating 90°, or exceeding it. The torpedo-boat destroyer *Farragut* is a case of a vessel in which, relatively speaking, the beam and the freeboard are both high. It also has, for such a small vessel, a good metacentric height. It will be observed that the range of stability is very great indeed, the righting arm remaining in all cases very considerable, even at an inclination of 90°.

Stability in Battle.

In most modern warships the center of gravity is usually near the load waterline, or slightly above, usually being higher when the ship is light than when it is loaded. Hence, it may be said, in a general way, that in most of our warships, the addition of small weight decreases the initial stability, if it is placed above the load waterline. An application of this remark is in preparing a ship for action. Getting rid of the top hamper by either placing it below under the protective deck, or by dropping it overboard will, in general, tend to increase the initial stability of the ship, which is desirable in the circumstances of action. An example of this is the boats of the ship, which, on any ordinary cruiser or large vessel, will usually weigh from 15 to 30 tons. They are invariably and necessarily placed high on the vessel, and, if they can be dropped overboard, it will give just that proportional additional metacentric height to the ship, which corresponds to their position above the center of gravity.

If, as may sometimes be the case, the ship is considered a "tender" one, it may be advantageous, before action, to fill the compartments of the double bottoms with water. But this must be very carefully considered before it is undertaken. While, such an addition of weight to the bottom of the ship will almost invariably increase the initial stability, it will have several disadvantageous results. It is presupposed, and must be carefully attended to, that the water let into the double bottoms completely fills the double-bottom compartments; otherwise, the partial filling of the bottoms may, instead of increasing the initial stability, materially diminish



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it. The first disadvantage of a full double-bottom compartment is, in case of an explosion of a torpedo or a mine under the bottom, that the solid water contained transmits the shock to the inner skin, which will thus be much more readily ruptured (causing the possible sinking of the ship) than if the compartments were only filled with air, in which the gases due to the explosion could expand. The second consideration is that the addition of a considerable quantity of water in the bottoms materially increases the draft, thus lowering the protective deck relatively to the outside water and increasing the displacement. The first result may, in case of waterline damage, allow a much greater volume of water to penetrate on top of the protective deck, which may make the difference between the ship "turning turtle" or not. The increase of displacement will result in a corresponding decrease of speed.

Thus, for the circumstances of action, it will be necessary for the commanding officer to carefully consider the advantages and disadvantages of the admission of water into the bottoms, and to decide intelligently on this subject, he must be acquainted with the qualities of his ship and all the attendant circumstances that are liable to occur. It may be said, in conclusion, that if the weather is rough and a heavy sea running, it will, in general, be desirable for him to have a greater stability than if the sea is perfectly smooth.

Another question that may arise in preparing for action is the distribution of coal. Nearly all modern vessels have both upper and lower bunkers. The upper bunkers are above the protective deck and are supposed to act as a partial protection against the enemy's projectiles. Not only is this so, but the coal itself acts to exclude just such an amount of water and to prevent its having a free surface. The explosion of shells in coal has been found to have little effect in displacing it, and the coal was not set on fire by them. At the same time, the metacentric diagram considered will show that, if the coal is in great part carried in the upper bunkers, the initial stability is less than when the coal is in the lower bunkers.

Effect of Shifting Weights.

The effect on stability and trim, of shifting weights, comparatively small in relation to the displacement, has been considered in Chapter V. If these weights assume considerable proportions relatively to the displacement, such as to cause very considerable inclinations or changes of trim, the metacentric method is no longer applicable. If such weights are added on the middle longitudinal plane of the ship, they will not (unless they render the ship unstable by reason of the rise of the center of gravity) cause it to be inclined. But, unless they are in the vertical through the center of gravity of the load plane, they will cause a change of trim. If they are not sufficiently far forward or aft to make a great change in the trim, such change may be calculated from the longitudinal metacentric height in the manner explained above. If it became necessary to discuss great alterations of trim, a diagram of the cross curves of stability, similar in its general type to that for transverse inclinations, would have to be constructed. It may also be remarked that the usual cross curves of stability are calculated for the normal trim of the ship, and any serious alterations of the trim will change the character of these curves to a considerable extent, the net result being, with the usual type of vessels, that this transverse stability will be diminished both in the righting arm and in range.

If, however, the change of the trim is not so great as to falsify materially the cross curves of transverse stability, they may be utilized to find the position of equilibrium of the ship at very considerable angles of heel.

The details of such calculations will not be gone into.

Without any actual damage to the skin of a ship, water may find its way into the interior through open ports or scuttles in the side, or open hatchways in the decks, the result being a more or less serious decrease of stability. Such occurrences are exceptional, but they have happened in ships caught by squalls of wind in comparatively smooth water. The British training ship *Eurydice* is an example.

The only thoroughly satisfactory way of making a complete investigation of the stability in a damaged condition, with free

water surface, is an experimental method in which small-scale models of the vessel under construction are used. The manner in which these experiments are made and the results obtained treated to determine the stability in a damaged condition are explained in detail in a paper by Mons. L. E. Bertin in the Transactions of the American Society of Naval Architects and Marine Engineers for 1894.

The mathematical treatment of the curves of stability as determined by Mons. Bertin will not be gone into, but, by the method developed by him, a very complete study of the stability in damaged conditions can be obtained.

It is remarked by Mons. Bertin, as the result of his investigations, that it is usually found that the danger of the vessel's upsetting was much greater than that of its sinking directly. In the modern type of war vessels with a protective deck this will be generally found to be the case. Such reports as are available as to the Battle of Tsushima indicate this result.

Let us consider how the naval architect endeavors to prepare his vessel for action so as to prevent this "turning turtle." It may be remarked, before proceeding further, that the subdivision of a man-of-war can be rendered much more elaborate than of a merchant vessel. This is, moreover, in the man-of-war, a fundamental necessity, as is also the watertight deck, called the protective deck, to protect the vitals of the ship from damage by explosion of shell above the water. It is a necessity of the case that this deck should be complete and have as few holes in it as possible. It is accordingly made water-tight. This protective deck is usually below the designers waterline at the sides, and, at the middle, is above the designers waterline. Above this is always another deck, usually some distance above the waterline, which, in our service, is usually the second deck and in our latest ships is also armored. This horizontal slice of the vessel in the waterline region has come to be known as the *raft-body*.

As projectiles are most likely to admit water above the protective deck in the space of the raft-body, the additional load of water will be usually high. At the same time, the waterline area to provide initial stability will be decreased in a number of com-

partments in communication with the sea; while the protective deck, if it remains intact, will prevent the water from penetrating into the lower part of the ship. It will thus usually arise that the stability vanishes before the floating power of the ship is very seriously impaired. In a merchant ship no such deck as the protective deck ordinarily exists, and the designer is free to make his water-tight subdivision by multiplying athwartship bulkheads.

This latter method, considered from the point of view of the stability and flotability of the ship, careful investigation will show to be the best for that purpose. But, in a man-of-war, there are limitations which necessitate the multiplying of the longitudinal bulkheads, and, as these longitudinal bulkheads have to exist, they are utilized, as far as possible, to multiply the number of water-tight compartments. The great necessity for longitudinal bulkheads exists principally in the fact that it is very desirable to group the machinery and coal in several units, so that, if a certain number of them are paralyzed in action, the remainder will still be available to permit the ship to retreat out of action, or even possibly to vanquish the enemy, more disabled than itself.

The longitudinal center-line bulkhead of a ship has been a matter of great controversy since the cellular subdivision of ships became established as current practice. While space does not permit entering into a detailed discussion of the considerations involved in the stability curves, it may be said, as a result of such investigations, that a longitudinal center-line bulkhead forming compartments in which water is free is not advantageous, if it be practicable to utilize the same weight in more closely spacing the transverse bulkheads in the ship. It is, however, sometimes necessary in order to isolate the machinery into independent groups.

The force of circumstances has therefore generally compelled the designers of ships to make a raft-body, and endeavor by all means in their power to prevent the water from penetrating into the ship below protective deck. The chief danger to be guarded against, therefore, is that of "turning turtle." This has been accomplished in two principal ways: One by the use of cofferdams, and the other by the use of extensive cellular subdivision in the raft-body. In the U. S. Service, the cofferdams have been placed where, it is

believed, they should be, that is, just inside the outer skin of the ship, and they have been filled with an obturating material which has been the corn-pith cellulose. In the British service, the cofferdams are usually placed around the hatches, and are kept empty, the idea being principally to prevent the water, when admitted on the deck, from penetrating below, by stuffing places between the two walls of the cofferdams with any material that comes handy to stop the leak.

The second method is by extensive subdivision of the raft-body. It is assumed that, if the projectiles penetrate, only a small number of cells will be broken into, either by holes made directly by the projectile, or by the explosion of shell. The reduction of the waterline area will thus be limited and will not be sufficient to destroy the initial stability.

A consideration of all that has gone before shows us the immense importance of the watertight subdivision of a man-of-war which is liable to damage in action. Such watertight subdivision, however, may be rendered nugatory through the multiplicity of openings through supposedly watertight bulkheads, such as doors or openings for ventilation. The very great importance of this matter is sometimes not realized, and the tendency is to multiply the number of doors and other openings. It has been known to occur that small holes have been cut through watertight bulkheads without any provision whatever for stopping them, thus reducing the efficiency of the cellular subdivision.

It has therefore become the practice to have the designer provide ships in service with a list of the openings, doors, scuttles, valves, etc., which should be kept closed in action, and others, which, after consideration, must be kept open in action. It is of course essential that there should be a reasonably free communication in certain parts of the interior of the ship during action. It will therefore be necessary to have a number of watertight doors and scuttles open in action, but the number of these can be materially reduced by a careful consideration of the plans of the vessel and the study of results obtained in drills and exercises during times of peace.

Nor are such considerations to be neglected in ordinary cruising, and it is urged upon all who go to sea in ships to study how they

may maintain the maximum of watertight subdivision at all times. It should be looked after that watertight doors and other openings not actually in use for passage or ventilation, especially in the raft-body and below the protective deck, are kept closed and closed *watertight*. When such precautions are observed, the commanding officer may feel reasonably sure that no such disaster will overtake his ship as that which occurred to the ill-fated British battleship *Victoria*.

Dynamical Stability.

The dynamical stability of a vessel, at any angle, is the work done upon that vessel in heeling her over to that angle = weight of ship $\times$ vertical separation of C. G. and C. B.

Moseley's formula for dynamical stability:

Refer to Fig. 29 (the statical stability figure). Here, the ship being inclined at an angle θ,

B has moved to B^1 or been lowered by an amount $= B^1Z - BG$

G has remained constant in location,

If $W =$ weight of ship

(1) Dynamical stability $= W\,(B^1Z - BG)$

But (2) $B^1Z = B^1R + RZ = B^1R + BG \cos\theta$.

Let $v =$ volume of immersed or emerged wedge

$V =$ volume of ship's displacement

Then $v\,(gh + g^1h^1) = V \times B^1R$

$$(3)\quad B^1R = \frac{v(gh + g^1h^1)}{V}.$$

Therefore, from (2) $B^1Z = \dfrac{v(gh + g^1h^1)}{V} + BG \cos\theta$.

Therefore, from (1) Dynamical stability $= W\left(\dfrac{v(gh + g^1h^1)}{V} - BG\,(1 - \cos\theta)\right)$.

The dynamical stability of a ship at any given angle is equal to the area of the curve of statical stability to that angle, i. e., dynamical stability is the integral of the statical stability. The demonstration of this, being somewhat intricate, is not given; but

from the above statement it will be seen that not only the range of the statical curve, but also the area, is of importance as indicating the work to be done to heel the ship.

For further treatment
Stability of Ships, Sir E. J. Reed.
Theorie du Navire, E. Guyon.
Theorie du Navire, Pollard & Dudebout.

CHAPTER VII.

STEERING AND TURNING OF SHIPS.

Ships are turned by means of rudders, sails, or screws. The two latter methods are generally used only as complementary to the rudders or when the rudders are not available, or in making a berth where the ship has not steering way from her forward motion.

Rudders, in the U. S. Service, are always placed at the stern of the vessel, the necessity not having arisen, in the types of vessels now in service, for bow rudders.

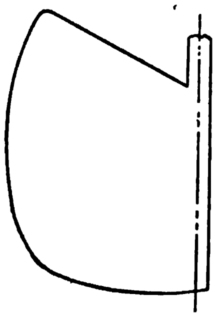


FIG. 40.

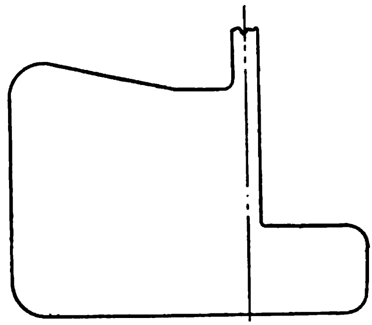


FIG. 41.

Rudders are of two general types:

(1) Ordinary rudders, turning about an axis at the forward edge, fitted in general on ships such as *Brooklyn, Columbia, Denver, Iowa,* and *Olympia,* and the older torpedo craft. (Shown in outline in Fig. 40.)

(2) Balanced rudders, or rudders a part of whose area is forward of the axis of rotation, fitted on most of our recent battleships, large cruisers, and destroyers. (Shown in outline in Fig. 41.)

The balanced rudder is made in several different forms, from the mechanical necessities of the special case to which it is applied.

The use of balanced rudders decreases the torque required to put the rudder over to a given angle.

Supposing the vessel to be moving ahead: Setting the rudder

oblique to the line of advance of the vessel, introduces, owing to the impact of the stream lines of water on the rudder surface, certain forces which cause the ship (1) to heel, (2) to turn, (3) to retard in speed, (4) to move sidewise.

This may be illustrated by the following sketch: (Fig. 42).

If rudder AB be set at angle θ with keel line AX, the stream lines following the side of the ship will meet the rudder at an angle, and impinging on it, exert on it a certain force. The amount of the force varies with the area of the rudder, the square of the speed of the water relative to the rudder, and the angle to which the rudder is placed.

The friction of the water against the side of the vessel causes it to move slightly with the vessel; therefore, in sailing ships, the

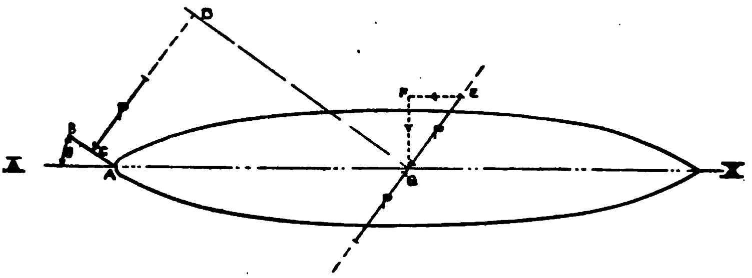


Fig. 42.

speed of this water is somewhat less than the speed of the vessel itself.

This same friction obtains in steamships, but as the action of the propellers causes the water to move astern, there may be with screws turning, a force acting on the rudder even before the ship itself has begun to move.

The shape of a vessel's run, *i. e.,* the after underwater body, has considerable influence on her steering, an easy run giving better steering qualities than a full run.

Referring now to Fig. 42:

If P be normal pressure acting on rudder through its resultant center of effort, C,

Let G be a vertical axis through CG of ship;

At G, therefore, we may introduce two equal and opposite forces, P, parallel to the other force on rudder. Then we have acting on the vessel:

(1) A couple, force, P, arm GL tending to turn,

(2) A force, P, acting through G in line EG.

We may further resolve this (2) into

(3) A force, $EF = P \sin \theta$ parallel to keel and opposite to line of advance and therefore tending to retard her motion.

(4) A force, $FG = P \cos \theta$ perpendicular to line of advance, tending to cause sidewise motion.

Heeling Due to Putting Over Rudder.

When the rudder is first put over, the force, P, tends to cause

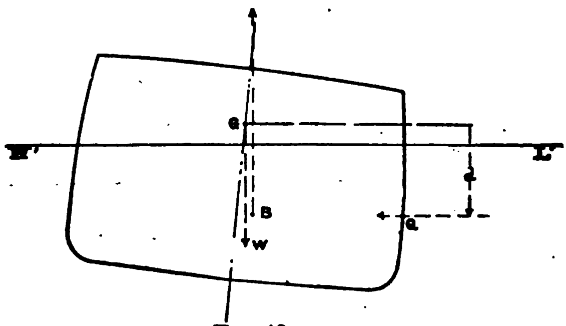


FIG. 43.

heeling inwards. This is especially noticeable in destroyers and other vessels having relatively large rudder areas.

In large ships, this inward heeling is generally followed by an outward heeling, due to centrifugal force setting outward through the C. G. of ship, which is generally above the center of pressure of water on the outside, called *center of lateral resistance*. This outward heeling tendency is resisted by the stability of the ship. This may be illustrated by Fig. 43.

In the above are indicated the forces acting after the vessel has started turning, independent of the forces on the rudder.

The angle of heel which a vessel will take up is approximately

$$\sin \theta = \frac{1}{11} \times \frac{d}{GM} \times \frac{V^2}{R}.$$

Where d = vertical distance between C. G. of ship and center of lateral resistance

GM = metacentric height (transverse);
V = speed in knots on turning circle;
R = radius of turning circle in feet.

From this equation it will be noted that the heeling on the circle varies:

(1) *inversely* as metacentric height;
(2) *directly* as *square* of speed;
(3) inversely as radius of circle.

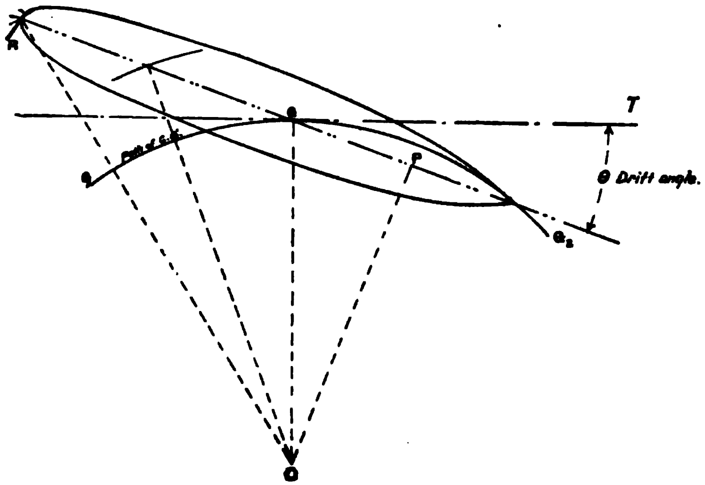


FIG. 44.

It is often found in destroyers and torpedo boats where the distance, d, above, is not great, that the outward heeling tendency due to centrifugal force is overcome by the inward heeling tendency due to pressure on the rudder whose center of pressure is below the center of lateral resistance. Care should be taken in such vessels not to right the rudder too soon in turning, or the vessel may give a dangerous list outboard.

Drift Angle and Pivoting Point.

When a ship is turning in a circle, the fore and aft center line points inside the circle; therefore, the propelling force is delivered

in a direction oblique to the motion of the vessel. This is a further reason for reduction of speed of a vessel in turning.

The ship being at any instant as shown (Fig. 44).

G_1GG_2 being path of C. G.

O being center of this path

Draw GT tangent to path at instantaneous position of G,

Then PGT is *drift angle;*

From O draw perpendicular to longitudinal center line of ship. Then P is *pivoting point* at drift angle $= \theta$.

The motion of any point in the ship is instantaneously in the direction of the tangent to the circle in which that point is turning.

All points abaft P will, relative to P, move to port.

All points forward of P, will, relative to P, move to starboard.

Path of Ship in Turning.

The rudder of a ship being put over, the ship begins to turn in a spiral path. By the time she has turned 8 points, the path is approximately circular.

The distance from the position at which the rudder is put over, to position at which she is moving perpendicular to her original course, is called the advance.

The distance from the original course to the position where she has turned through sixteen points is called the Tactical Diameter.

The turning of a ship is influenced by:

(1) Time of putting rudder over.
(2) Rudder angle.
(3) Size of rudder.
(4) Moment of resistance of underwater body to turning.
(5) Moment of inertia of ship.

CONSIDERING (1) With modern steering gears, this is a very short time. This time is reduced by the use of balanced rudders, bringing the center of effort closer to the axis of rotation and offering but small resistance to being put over.

CONSIDERING (2) Stops are usually placed, in the U. S. Service, limiting the rudder angle to 35°. The tactical diameter varies roughly inversely as the rudder angle, so a larger tactical diameter may be obtained by using a smaller rudder angle.

CONSIDERING (3) As pressure, P, depends on size of rudder, this is obvious. It is usual to express the rudder area as a fraction of the area of immersed middle-line plane of the ship. The following table indicates ordinary values of this ratio:

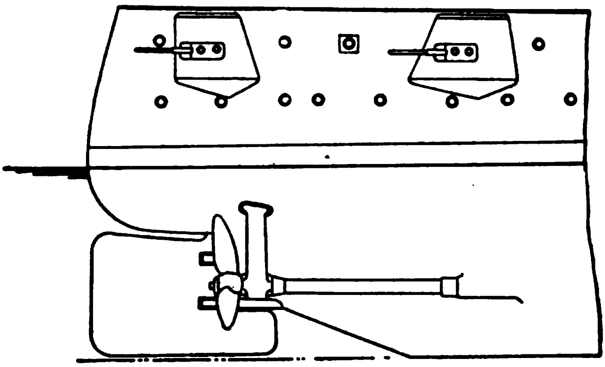


FIG. 45.

Battleships	1/37
Large cruisers	1/45
Small cruisers	1/41
Destroyers	1/31

CONSIDERING (4) Resistance to turning depends on shape of underwater body and the position of pivoting point. This is generally well forward.

As the moment of resistance offered by any portion of the surface varies roughly as the cube of its distance from pivoting point, times cosine of the angle which it makes with the vertical,

the flat portions at after end offer the best resistance to turning. This explains the reason for cutting away the after end of vessels to allow of under-hung balanced rudders, as shown in Fig. 45.

A short ship will turn more rapidly than a long ship.

A ship trimming more by stern than usual will have larger tactical diameter than when in her normal condition.

CONSIDERING (5) A ship with heavy weights at bow and stern will turn more slowly than one whose weights are concentrated amidships, and will return to her original course more slowly when once turning.

The usual values of tactical diameters for vessels, of various classes, in the U. S. Service, both engines operating at full speed ahead, are as follows:

	Tactical Diameter (about)
Battleships (length about 500 feet to 550 feet)	600 yards
Armored cruisers (length about 510 feet)	615 "
Protected cruisers (length about 320 feet)	610 "
Monitors (length about 250 feet)	220 "
Torpedo-boat destroyers (length about 300 feet)	600 "

The turning of twin-screw ships may be greatly aided by running the engine on side towards which rudder is put, astern, and on the other side, ahead.

Turning trials are carried out on final trials and after commissioning of vessels. The method of conducting these trials is covered in the seamanship course.

CHAPTER VIII.

THE OSCILLATIONS OF SHIPS.

Introductory.—The main object in studying this branch of Naval Architecture is to ascertain what elements govern or affect the rolling motions of a vessel in a seaway, so that her probable safety at sea may be secured in her design. But in approaching this question, although it is evident at once that a ship will experience resistance when rolling through the water, it is convenient to consider *first,* the purely hypothetical case of a vessel rolling *unresistedly* in *still* water, where the only two forces acting upon her are the equal ones due to her weight and buoyancy; *second,* to ascertain, by means of experiments on actual ships or models in *still* water, in what respects the conclusions arrived at in the first case are modified by the operation of resistance; and *third,* to see in what manner the oscillations are affected by the presence of waves.

The principal oscillations of ships take place in the transverse and fore-and-aft directions; in the former case the motion is called *rolling,* and in the latter *pitching* or *'scending* according as the bow of the ship moves downward and the stern upward, or *vice versa.* Of these oscillations rolling is much the more important, and will alone be dealt with for the present.

The extent of the rolling motion is measured by the inclinations which the ship reaches from the upright, and in swinging from her extreme inclination on one side of the vertical to her next extreme inclination on the opposite side, that is, a single swing from starboard to port, or *vice versa,* she is said to perform an *oscillation.* The *arc of oscillation* is the sum of the angles on either side of the vertical swept through by the ship in an oscillation, and her *period* is the time occupied in performing one oscillation.

Parallelism between motions of a ship and a simple pendulum.— There is an obvious parallelism between the motion of a ship set rolling in still water and that of a simple pendulum swinging in a resisting medium. Apart from the influence of resistance, both ship and pendulum would continue to swing from the initial angle of inclination on one side of the vertical to an equal inclination on the other side; and the rate of extinction of the oscillations in both depends on the resistance, the magnitude of which depends on several causes to be mentioned hereafter.

Length of simple pendulum with which oscillations synchronize.—Supposing the rolling of a ship in still water to be unresisted, it may be asked what is the length of the simple pendulum with which her oscillations keep time, or synchronize? Sometimes it has been assumed that a comparison between a ship held in an inclined position and a pendulum of which the length is equal to the distance between the center of gravity and the metacenter held at an equal inclination will remain good when the ship and pendulum are oscillating. In fact, it has been supposed that the whole of the weight may be concentrated at the center of gravity while the metacenter is the point of suspension for the ship in motion as well as for the ship at rest; but this is obviously an error. If it were true, the stiffest ships, having the greatest metacentric heights, should be the slowest swinging ships; but all experience shows the direct opposite to be true.

The error of this assumption may be simply illustrated by means of a bar pendulum of uniform section suspended at one end, as in Fig. 46, having its center of gravity at the middle of its length. To hold this pendulum at rest at any inclination to the vertical must require a force exactly equal to that required to hold at the same inclination a simple pendulum of half the length of, and of equal weight to, the bar pendulum. This simple pendulum, considered as having all its weight concentrated at one point (the "bob"), which becomes the "center of oscillation," and supposed to be hung from the point of suspension by a weightless rod, if set swinging would be found to move much

faster than the bar pendulum; because, where in the bar pendulum its mass is not concentrated at any particular point (though at rest its weight acts through its center of gravity), but is distributed uniformly along its whole length, the center of oscillation does not coincide with its center of gravity but lies in a point two-thirds of the length of the bar distant from the point of suspension equal to the radius of gyration of the bar about its end.

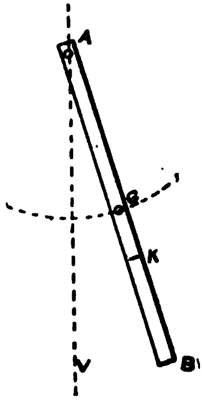


FIG. 46.

Position of the instantaneous axis of rotation.—A ship rolling in still water does not oscillate about a fixed axis corresponding to the point of suspension in one end of the bar pendulum; but if we may imagine in the swinging of the bar pendulum that the end before taken as the point of suspension swings about a fixed axis of rotation through the original center of oscillation, instead of the contrary, preserving the same relative motions of these two points, we will see more clearly the similarity between the motion of the pendulum and that of a ship oscillating about a longitudinal axis passing approximately through her center of gravity.

The position of the instantaneous axis about which a ship is turning at any moment, supposing her motion to be unresisted, and the displacement to remain constant during the motion, may be determined graphically, considering only the simultaneous motions of the "center of flotation" and the center of gravity. Let us imagine the ship to be supported at the bow and stern by projecting trunnions having perfectly smooth surfaces and their cross-sections of the same form as the "curve of flotation" and resting upon a rigid, perfectly smooth, and plane, water surface. Then the ship rolling on these trunnions will fulfill the conditions for unresisted rolling. The point of contact of the trunnion with the water surface will then be the "center of flotation" and point of support. This point has its instantaneous motion in a

horizontal direction and consequently the instantaneous center will lie in a vertical line drawn through it. Resistance being supposed non-existent, the only forces acting upon the floating ship are the weight and buoyancy, both acting vertically through the center of gravity; therefore the instantaneous motion of the center of gravity must be vertical, and the instantaneous center will lie on a horizontal line drawn through it. Hence it follows that the intersection of the vertical line through the center of flotation and the horizontal line through the center of gravity will be the instantaneous center of motion.

In warships the center of gravity ordinarliy lies near to the water-line for the upright position; and for oscillations of 12 or 15 degrees on either side of the vertical, the center of flotation does not move far away from the middle line of the load water plane. In other words, the common case for warships of ordinary form is that the instantaneous axis passes through or very near to the center of gravity. Although, as its name implies, the position of the instantaneous axis changes from instant to instant, it is sufficiently accurate to regard the ship as rolling about a fixed axis passing through the center of gravity.

The agents producing rolling.—We have seen that, besides the influence of the moment of inertia about a longitudinal axis passing through the center of gravity, the active agent in producing rolling, after a vessel has been once inclined and then set free, is the moment of statical stability. In the first place, to incline the ship requires the expenditure of *work* or *energy,* the amount of which can be ascertained from the curve of dynamical stability. Then in the inclined position she has acquired energy which she holds by virtue of her inclination from the vertical, which becomes a constant quantity during her rolling, since by the law of conservation of energy, if no external resistances act, the energy due to position combined with that due to motion remains a constant quantity.

At the position of extreme inclination there is no motion, and consequently her total energy is the dynamical stability in that

position. Upon reaching the upright she has no energy by virtue of position, all the dynamical stability having been converted into energy of motion. Finally, on coming to rest on the opposite side of the vertical all the energy she possesses is that due to position, so that the dynamical stability there must be equal to what it was in the first case when at rest at the extreme inclination on the other side of the vertical. That is to say, the ship must reach, on the opposite side of the vertical, an angle equal to that from which she first started. If, therefore, a vessel rolled unresistedly in still water, she would continue to oscillate from side to side without any diminution in the angle of roll from the perpendicular.

Isochronous oscillations.—Assuming that the front part of the ship's curve of stability is a straight line (an assumption which is approximately true in most ships up to 12 or 15 degrees), since then the value of the righting force varies directly with the angle of inclination, it follows mathematically that the *period* is the same for large as for small arcs of inclination within this limit of degrees on each side of the vertical; that is, she will swing through a total arc of, say 20°, in the same time as through one of, say 4°. This fact is expressed by saying that the ship is *isochronous* within the limits of roll mentioned above. For larger angles of oscillation such ships would probably have a somewhat longer period than for the small oscillations, and it is possible to approximate to this increase. Vessels of low freeboard or exceptional form may not be isochronous through arcs of oscillation so large as those named for ordinary vessels. For unresisted rolling the theoretical condition may be very simply stated: *Within the limits of inclination to the vertical for which the statical righting moment varies directly as the angle of inclination the rolling of a vessel will be isochronous.* In other words, if the curve of stability is practically a straight line for a certain distance out from the origin, the rolling will be isochronous within the limits of inclination fixed by that distance.

Determination of the period.—If the *period* be denoted by T, the *metacentric height* by m, and the *radius of gyration* about a longitudinal axis through her center of gravity by k—

$$T = \pi \sqrt{\frac{k^2}{gm}} = .554 \sqrt{\frac{k^2}{m}}.$$

A fair approximation to the still-water, or "natural" period of oscillation for a new ship is given by this formula. The metacentric height is determined for a warship as one of the particulars of the design; and the distribution of the weights is known, so that the moment of inertia can be calculated about the assumed axis of rotation passing through the center of gravity. This latter calculation is laborious, the weight of each part of the structure and lading having to be multiplied by the square of its distance from the axis; but with care it can be performed with close approach to accuracy. Calculations of this kind are rarely made except in connection with novel types of ships for which thorough investigations are undertaken in order to be assured of their safety and seaworthiness.

This formula given for the period supposes rolling to be unresisted; but the influence of resistance is much more marked in the extinction of oscillations than it is in affecting the period, and this accounts for the close agreement of estimates made from the formula with the results of experiments. Dr. Froude discovered that the period of the *Greyhound* remained practically the same after exceedingly deep bilge-keels had been fitted as it was without such keels.

Changes in period produced by changes in distribution of weights.—The preceding formula for the still-water period enables one to ascertain approximately the effect produced upon the period by changes in the distribution of weights on board a ship. Such changes usually affect both the metacentric height and the moment of inertia, and their effects may be summarized as follows:

Period is increased by—

(1) Increase in the radius of gyration;

(2) Decrease in the metacentric height.

Period is decreased by—

(1) Decrease in the radius of gyration;

(2) Increase in the metacentric height.

"Winging" weights—that is, moving them out from the middle line towards the sides—increases the moment of inertia and tends to lengthen the period. The converse is true when weights—such as guns—are run back from the sides towards the middle line. Raising weights also tends to decrease the moment of inertia, if the weights moved are kept below the center of gravity; whereas if they are above that point, the corresponding change tends to increase the moment of inertia. But all such vertical movements of weights have an effect on the center of gravity, altering the metacentric height, and affecting the moment of inertia by the change in the position of the axis about which it is estimated. It is therefore necessary to consider both these changes before deciding what may be their ultimate effect upon the period of rolling.

Character of fluid resistance.—An actual ship set rolling in still water differs from the preceding case in the addition of *fluid resistance* to its rolling.

This resistance may be subdivided into three parts: (1) *Frictional resistance* due to the rubbing of the water against the immersed portions of the vessel, and particularly experienced by the amidship parts where the form is more or less cylindrical. (2) *Direct* or *head resistance* due to the opposition offered to the passage through the water in a more or less flatwise manner of projections such as the keel and bilge-keels and the comparatively flat parts of the ship at the ends. (3) *Surface disturbance* or *wave-making resistance* due to the creation of waves as the vessel rolls, which cannot be propagated without the expenditure of energy, which must be supplied to the water by the ship, thus affecting her motion.

Estimation of the resistance.—The aggregate effect of these three parts of the fluid resistance displays itself in the gradual extinction of the oscillations when the ship rolls freely under the action of no external forces other than gravity. To estimate by direct calculation the value of the resistance for a ship of novel

form, or for any ship independently of reference to rolling trials of similar ships or *models,* is not, in the present state of our knowledge, a trustworthy procedure. The first two parts of the resistance may be calculated to a degree of approximation that is sufficiently accurate for practical purposes, but the third seems beyond calculation. When the character of the bottom is known—iron or steel, copper- or zinc-sheathed, clean or dirty—it is possible to obtain the "coefficient of friction" for the known conditions; then knowing the area of surface upon which this friction operates and the approximate speed of rolling, the total frictional resistance may be estimated. Similarly, when the "coefficient of direct resistance" for the known speed has been determined by experiment it may be applied to the total area of keel, bilge-keels, etc., and a good approximation made to the total direct resistance. But the wave-making part cannot be so treated, and so it becomes necessary to make rolling experiments in still water, in order that the true value of the resistance may be deduced from the observations. The importance of the deductions arises from the fact that fluid resistance has very much to do with controlling the maximum range of oscillation of a ship rolling in a seaway. This will be considered later; for the present it is sufficient to note that, if the rate of extinction of the still-water oscillations is rapid, the range of rolling at sea will be greatly reduced by the action of the resistance; but if the rate of extinction is slow, resistance will exercise comparatively little control over the behavior of the ship at sea.

Rolling experiments—how made.—The objects of rolling experiments are twofold: (1) To ascertain the period of oscillation of the ship; (2) to obtain the rate of extinction of the oscillations when the ship is rolling freely and being gradually brought to rest by the action of resistance.

Various methods may be employed to produce the desired inclination from the vertical, at which the rolling is left free and the observations are commenced. Small vessels have been "hove-down," and suddenly set free. Large vessels are usually rolled in still water by running a large number of men back and forth

across the deck, their motions being suitably timed so that the amplitude of the oscillations shall gradually increase. This method will be briefly described. The men should first be lined up along the middle line of the deck and then made to run out quickly to the side and back again, reaching the middle line again at the moment the maximum inclination of the ship occurs; they should then run up the deck to the opposite side, stay there as long as possible and get back to the middle line by the time the ship reaches her extreme angle on that side of the vertical. This is repeated several times. The movements of the men must be carefuly timed with the rolling of the ship so that, running at the same rate, and *always "uphill" from the middle line,* they will have run out and back again crossing the middle line by the instant that the vessel on her return roll has reached the upright. Obviously throughout this return roll the inclining moment due to the weight of the men acts with the righting moment due to statical stability and so increases the rolling motion. The arcs of oscillation will therefore be gradually increased, until a maximum is reached determined by the number of men, the number of runs, their transverse movement, and the resistance to rolling. The proper timing is usually effected by an officer standing in some prominent position amidships, such as on a hatch or other obstruction in the middle of the deck, carefully watching the rolling of the ship and at the proper instant directing the men to "starboard," "port," etc., and, when a sufficient angle of inclination is attained, to halt and stand steady on the middle line.

Observations made during rolling experiments.—After the men cease running, careful note is taken of the times occupied by the ship in performing each of several successive single rolls. For vessels of ordinary forms, and for the arcs of oscillations reached in still-water rolling, the periods noted for all the rolls are for practical purposes equal, and the motion is isochronous. Hence if n single rolls are noted in an interval of T seconds, the period is equal to $T \div n$. Careful observations are also made of the extreme angles of heel reached at the end of each oscillation, the difference between the successive values marking the rate of extinction. These

observations are usually continued until the arc of oscillation has diminished to 2 or 3 degrees.

Suitable automatic apparatus has been devised for recording the rolling motion of the ship in such a manner that the angle of inclination, at each instant of her motion, as well as her extreme angles of heel, can be traced, and the period also determined; but such extensive apparatus is not necessary ordinarily.

Curves of extinction.—The gradual degradation in the range of oscillation is commonly represented by means of what are termed

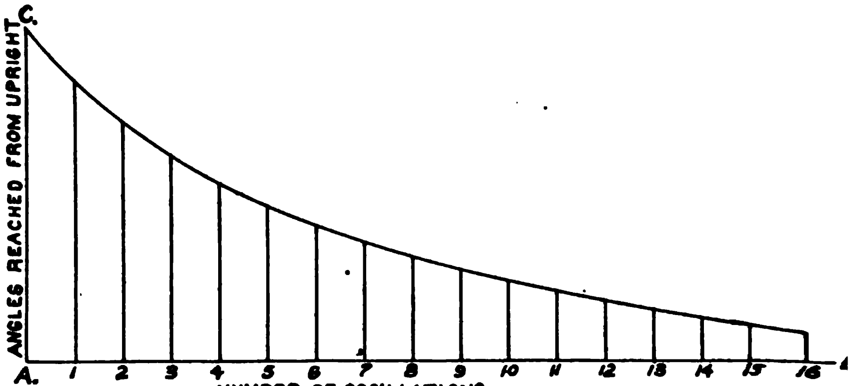


FIG. 47.

"curves of extinction," as shown in Fig. 47, which are constructed in the following manner: Rectangular axes are drawn, and on the horizontal axis are set off equal spaces, each division representing an oscillation; and since each oscillation is performed in the same period, each of these spaces also represents a certain number of seconds. The vertical axis is similarly laid off to scale to mark the angles of inclination. At each point of the horizontal axis representing the successive oscillations an ordinate is erected and the observed inclination at the end of that oscillation is marked on it to the scale used. A curve drawn through all such points is the curve required. The difference between any two successive ordinates gives the degradation of roll or *extinction value* in that par-

ticular oscillation, and the greater the resistance the greater will be this extinction value and the steeper therefore the curve.

Rolling experiments with models.—Similar rolling experiments are made with models; and a model of reasonable size and so weighted that it may have a time of oscillation proportioned to the period of the full-sized ship will have, it has been found by experiment, the same extinction value for corresponding oscillations and will come to rest after the same number of rolls, showing that rolling experiments on models may be substituted for those on the full-sized ship. There are many obvious advantages in such model experiments. They are more easily performed than with a full-sized ship; they may be made before the construction of the ship is begun; by them it is possible to test the influence of variations of form, or proposed changes in bilge-keels, etc.; and any critical conditions affecting the safety of a ship when damaged can be investigated.

Periods of various classes of war vessels.—Rolling experiments have now been made on most classes of warships and their natural or still-water periods have been determined. The following summary gives about the average values: For small gunboats, torpedo boats and small craft the period for a single roll, *i. e.*, ½ cyclic period, is from 2 to 3 seconds; these short periods being due to the small radii of gyration consequent upon the small dimensions, and to the necessity for securing a good metacentric height. For the larger gunboats and smaller cruisers, periods of from 3 to 4½ seconds are common. The latest U. S. destroyers have from 5 to 6 seconds. The larger unarmored cruisers average from 5 to 6 seconds, but some of the later swift cruisers have periods as high as 8 seconds, their metacentric heights being less than those of earlier types. Among armored ships the shortest periods are found in coast-defense ships of shallow draft, great proportionate beam, and large metacentric heights. One of our monitors was found to have a period of 3.7 seconds only, and some of the French floating batteries have periods of 3 to 4 seconds. The earlier types of coast-defense battleships have periods of 5 to 6 seconds, and the larger seagoing battleships and

armored cruisers, having less metacentric height and large radii of gyration, range from 7 to 9 seconds.

Surface disturbance.—Waves are constantly being created as the vessel rolls, and are constantly moving away, and the mechanical work done in this way results in a reduction of the amplitude of successive oscillations. Very low waves, so low as to be almost imperceptible owing to great length in proportion to their height, would suffice to account even for this large proportionate effect.

The importance attributed by Dr. Froude to surface disturbance derives considerable support from experiments made on very special forms of ships. For example, in experimenting upon the model of the H. M. S. *Devastation,* it was found that when the deck-edge amidships was considerably immersed before the model was set free to roll, the deck appeared to act like a very powerful bilge-piece, rapidly extinguishing the oscillations. Experiments made in the French navy showed that when bilge-keels were moved high up on the sides of a vessel, so that, as she rolled, the bilge-keels emerged from the water and entered it again abruptly, their effect became much greater than when they were more deeply immersed; as one would anticipate from the increased surface disturbance that must exist when the bilge-keels are so high on the sides. Experience with low freeboard monitors furnishes further support to this view, immersion of the deck and the existence of projecting armor developing greatly increased resistance and assisting in preventing the accumulation of great rolling motions.

Value of bilge-keels.—It has already been explained that direct resistance is experienced by the comparatively flat surfaces of deadwoods, keels, bilge-keels, etc., hence it follows that resistance to rolling may be considerably influenced by fitting such appendages. In fact, the use of bilge-keels has become the most common means employed to increase resistance to rolling and it will be of interest to examine into their mode of operation.

Direct experiment and careful observation have furnished unquestionable evidence in favor of the use of bilge-keels, showing that they will greatly increase the rapidity of the extinction of still-

water oscillations and limit the rolling of ships at sea, while it is also found that the period of oscillation is changed but little as the resistance becomes increased. An approximation can be made by the following formula to the work done by a bilge-keel during the swing of a ship. Assuming the resistance to vary as the square of the angular velocity, and r to be the *mean radius* of the bilge-keel from the axis of rotation (assumed to pass through the center of gravity)—

$$\left.\begin{array}{l}\text{Work done during}\\ \text{a single swing}\end{array}\right\} = \text{area of bilge-keel} \times r^3 \times \frac{4\pi^2}{3T^2} \times \theta^3 \times C$$

when $T =$ period, and $2\theta =$ arc of oscillation, and C a constant, which Dr. Froude took as 1.6 lb. per square foot with the velocity of 1 foot per second.

From the general form of this expression it is evident that the effect of bilge-keels increases with—

(1) Increase in area;
(2) Decrease in the period (T) of the ship;
(3) Increase in the arc of oscillation.

Also, having regard to the formula for the period given on p. 106, it will appear that the effect of such keels increases as the moment of inertia is diminished or the metacentric height increased, both of which variations shorten the period T.

Number and arrangement of bilge-keels.—Warships and some classes of merchant ships are now commonly fitted with bilge-keels. Usually one such keel is fitted on each side, near the turn of the bilge, and carried as far forward and aft as may be convenient. On our more recent ships of great beam it has been necessary to omit a great part of this keel near [illegible] so as not to interfere with docking, and it is usual to prescribe that no part of the bilge-keel shall project beyond the contour line of the greatest section.

In some cases two keels have been fitted on each side, but there are objections to this arrangement. Two shallow keels have much less power in extinguishing oscillations than a single deep keel of area equal to the combined areas of the other two; and there is a difficulty, except in large ships, in placing two keels on a side

sufficiently clear of each other without the risk of emersing the upper one during rolling.

The reason for the comparative loss of power in two shallow keels is easily seen. As a bilge-keel swings to and fro with the ship it moves at varying velocities, and impresses accelerating motions on masses of water with which it comes in contact, these accelerations being the equivalent of the resistance. If there be two bilge-keels on each side, the water encountered by one will probably have been set in motion by the other and consequently their combined resistance is less than the sum of the resistances which they would experience if acting singly both in undisturbed water.

Effect of emersion of bilge-keels.—As regards the emersion of bilge-keels it is necessary to remark that more or less violent blows or shocks are received by such keels as they enter the water again; and even when no structural weakness results, the noise and tremor are unpleasant.

The power of side-keels placed near the water-line is very great, but for the reasons given they are rarely used; and in cases where an overhanging armor-shelf a few feet below the water-line acted as a side-keel, it has been found desirable to fill in under the shelf in order to diminish the shocks of the sea.

Size of bilge-keels.—Practical considerations usually determine the depths given to bilge-keels. Relatively deep keels require to be strongly constructed and attached to the hulls, since their extinctive effect on rolling is necessarily accompanied by considerable stresses on the material. In vessels of great size the limit is fixed by the necessity for compliance with certain extreme dimensions fixed by the docks which the vessels have to enter. Bilge-keels are, of course, of least importance in ships of large size and considerable inertia. In small vessels where the periods of oscillation and the moments of inertia are small, bilge-keels are most effective. In vessels where they can be conveniently fitted their influence cannot be other than beneficial.

For a given area of bilge-keels the extinctive effect varies with the cube of the angle of oscillation and consequently that effect

increases very rapidly as the angles of swing increase. In still water large angles of oscillation do not occur, but among waves the contrary is true and it is under these circumstances that the full value of bilge-keels is illustrated.

Effect of change of trim on speed.—As the bilge-keels are fitted for the normal trim of a ship any marked departure from this trim will tend toward making them a drag with consequent ill effect on the speed. Model tank experiments, however, indicate that for any usual change of trim either by bow or stern such effect is not serious and may be neglected.

Effect of "water chambers."—Other means have been devised for checking rolling, and for small oscillations some of these are more effective than bilge-keels; but, on the whole, bilge-keels are the simplest and most effective means of limiting rolling motions which can be taken in addition to those which lie in the power of the naval architect in regulating the stability or the period of oscillation.

For certain classes of ships having large metacentric heights and comparatively short periods of oscillation, the plan of fitting a "water chamber" has been tried. H. M. S. *Edinburgh,* a central-citadel turret-ship, with which very extensive experiments were carried out by the British Admiralty, may be taken as a typical case. Above the protective deck in that vessel a "water chamber" was built 16 feet long fore and aft, and 7 feet high; its breadth could be varied by bulkheads from the entire breadth of the vessel at that part, 67 feet, to either 51 feet or 43 feet. Using each breadth, the chamber was partially filled two or three times to different depths giving various quantities of water, and rolling experiments made, which proved that water chambers exercise a great extinctive effect at small angles of rolling, for which bilge-keels have little influence; that at larger angles (up to 12 degrees of heel) a considerable increase of depth of the bilge-keels actually fitted to the *Edinburgh* would have been needed to give an extinctive effect equal to that of the free water in the chamber; for still larger angles the bilge-keels gained rapidly on the water chamber; that increase in breadth was accompanied by a great increase in extinctive effect. The most effective depth of water was shown to be

that which would permit the transfer of the water from side to side to keep time with the rolling motion of the vessel, the water always moving so as to retard the rolling. This motion of the water to produce the best results should be the reverse of that described for the men running in a still-water rolling experiment. Instead of acting *with* the moment of the righting couple, it should act *against* it during each return roll and thus retard the motion of the vessel.

Frahm anti-rolling tanks.—The water chamber system as applied to the *Edinburgh,* was never extensively used, but a system somewhat similar in principle has recently been devised by Dr. Herman Frahm of Hamburg, Germany, which has been used with advantage in a number of freight and passenger steamers and is being fitted to some warships as a means of securing steady gun platforms.

This device also employs water for quelling the rolling motion but avoids many of the disadvantages of the water chamber of the *Edinburgh* type and is said to be far more efficacious against rolling.

The result is obtained by the application of the laws of synchronism.

It is characteristic of synchronism that bodies that can oscillate about a condition of equilibrium will be made to swing severely under impulses of comparatively small energy if the period of oscillation of the impulse synchronize with the individual periods of the respective bodies.

The phase of oscillation of the body and of the impulse are deferred by 90 degrees.

The law may be demonstrated on a special apparatus based on the well known double pendulum.

A ship constitutes a body of this kind, as she will oscillate under the impulse of the waves. A ship when rolling will heel exactly or nearly exactly in the periods of her individual oscillations. This has been proved by practical observations at sea and confirmed by experiments on models, from which it has resulted that a ship will roll in her individual number of oscillations, even if the impulse of the waves be more or less irregular.

Large rolling amplitudes observed in practical seafare are due probably to the influence of synchronism between waves and vessel.

On this fact the Frahm device has been based. It utilizes a secondary and artificial synchronism in order to annihilate the influence of the primary synchronism between waves and ship.

This secondary synchronism is introduced by means of an U-shaped tank, located athwartship from side to side, in which a water column can oscillate with the same number of swings per minute as are peculiar to the ship herself. The tank is designed in the form of a communicating tube (see fig. 48) and consists of 2

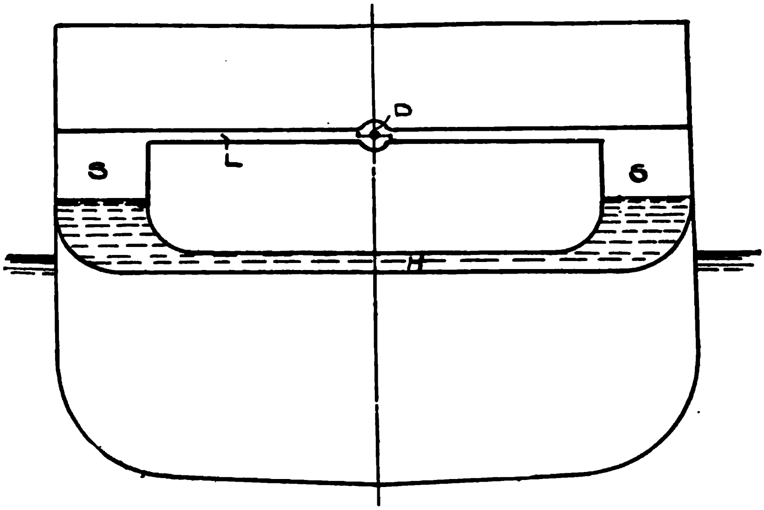


FIG. 48.—DIAGRAMMATIC ARRANGEMENT OF FRAHM ANTI-ROLLING TANK.

parts (S) at both sides and a connecting part (H). The water is to fill the latter entirely and the vertical basin about one-half.

The individual number of oscillations of the water column will of course depend on the dimensions of the whole tank and it is the designer's task to calculate them accordingly.

The effect of this device, and principally the influence of the secondary synchronism, can be explained through the aforesaid experimental apparatus by simply adding a third pendulum.

According to the law of synchronism the phases of the impulse of waves and the ship are deferred by 90 degrees, that is to say

the ship lags a quarter of her full period behind the wave, or in other words the ship arrives at the maximum heel a quarter of a period later than the wave in its advancing movement is at its maximum slope towards the ship.

The same law naturally applies to the swings of the ship and the oscillating movements of the tankwater by the former. Also in this instance the phases are deferred by 90 degrees or the tankwater will reach its highest or lowest level in the vertical parts a quarter of a period later than the greatest heeling of the ship to one or the other side.

Consequently there results a total difference between the impulse of the waves and the oscillations of the tankwater of 90 degrees plus 90 degrees, or 180 degrees; the latter will act just in opposite direction to the impetus of the waves. The ship thus will heel only as far as the tankwater, due to secondary synchronism, will rise or lower in the vertical basins to such an extent, that the heeling moment imparted to the ship by the waves is balanced by the opposite turning moment produced by the oscillations of the tankwater.

The increment of heeling, resulting on an unquelled vessel from impulse to impulse, cannot take place now, and the rolling motions are limited to such as will be sufficient to produce the necessary oscillations of the tankwater in accordance with the foregoing explanation. Big ships have been known to have quelled the rolling down to $\frac{1}{3}$ by simply putting on their anti-rolling tanks.

A great advantage of this invention is that only a small connecting passage is required from side to side, whereas the *Edinburgh* type of water-chambers wholly occupied the space from side to side for a full deck height.

A connection (L) between the upper parts of the vertical tanks is also fitted, provided with a throttling apparatus (D) and is of great importance. It serves first of all for stopping the movements of the tankwater by simply blocking the connection. Besides the air passing through the upper connection in accordance with the rise or fall of the water in the vertical basins can be throttled more or less in order to adjust the oscillation of the tankwater as may suit best to the sea then running.

Figure 49 shows the construction of the quelling tank on a modern 26,000 ton battleship. From fig. 49, showing a cross-section of the ship, it will be seen, that the tank follows the double-bottom, the latter being carried up to armor-deck. The cross connection is 22 inches high and graded into the lateral basins, being each about 6 feet 6 inches wide. Between the inner-skin of the lateral basins and the longitudinal torpedo-bulkhead an accessible passage of $31\frac{1}{2}$ inches width is left.

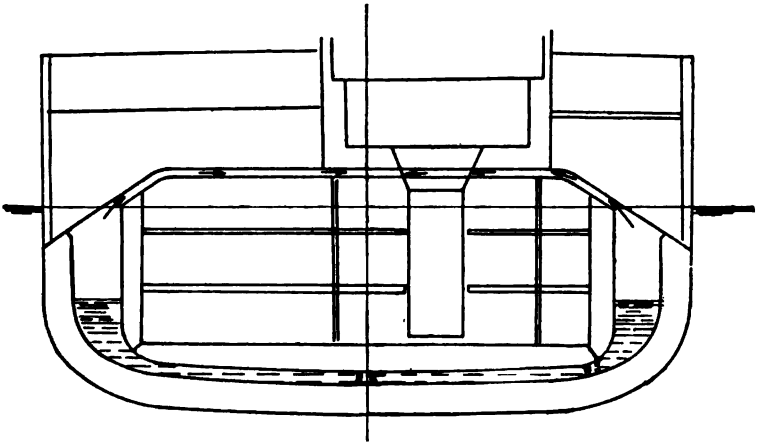


FIG. 49.—ARRANGEMENT OF FRAHM ANTI-ROLLING TANK AS APPLIED TO A BATTLESHIP.

The air-connection is located between the deck-beams below armor-deck. The throttling apparatus, in form of a valve, can be operated from the center-line-passage.

Thornycroft's automatic steadying apparatus.—If a weight were moved transversely across a ship as she rolled, and its phases of motion were the converse of those described for the motion of men in a rolling experiment, then it would exercise an extinctive effect resembling that obtained when the water in a chamber has its maximum influence. In other words, if at any moment the moving weight is so placed as to act against the righting moment of statical stability, this virtual diminution of righting moment must diminish the rolling. Various attempts have been made to utilize

this idea; most of them have failed because no efficient controlling apparatus has been devised which would secure the appropriate motions of the weight, more particularly in a seaway. Failure in this respect might result, of course, in increased rolling and possible danger. Sir John Thornycroft succeeded however in solving this problem and gave proof of his success by the behavior of a yacht fitted with his apparatus. His success lay on the side of the mechanical controlling gear, in which Sir John Thornycroft exercised great skill and ingenuity, the gear being automatic in its action, and practically incapable of error.

The gyroscope has been favorably considered for reducing the rolling of ships.

Gyroscopic installations are in general of two types, passive and active.

Both depend on the well known property of the gyroscope.

In the Schlick or passive type, *i. e.*, a gyro free and uncontrolled as to its precessional movements. The periodic motions of the ships are damped after they have been developed by the sea, since that is the only force tending to disturb the gyro and excessive rolling is thereby prevented.

The machine as installed consists essentially of a heavy wheel mounted on a vertical axis within a ring swung on horizontal gimbals attached to the ship. As the ship rolls the ring tilts, thereby setting up the couple, tending to right the ship.

In an actual installation it was found necessary to fit braking and damping devices to control the ring from swinging violently to and fro.

In an article before the Institute of Naval Architects of Great Britain in 1904, Dr. Schlick cites an example of a designed installation on a vessel of 5900 tons, the weight of which was about 20 tons.

The Sperry type of active gyro stabilizer has recently received favorable consideration.

This is so called to distinguish it from the passive type used for the same purpose by Dr. Schlick.

In the Sperry active type gyro, the purpose is to correct each individual increment of roll in its beginning and thus prevent the ship taking up any motion. This is done by controlling the preces-

sional movements of the gyroscope by an exterial prime move and a precession engine.

The Sperry installation takes up but a modest amount of space and weighs less than one per cent of the ship's total displacement. When stabilizing the mechanism receives its inciting impulses from the waves themselves.

Briefly the active force employed is centered in a large rapidly revolving fly-wheel in which the principal mass lies in the rim, and the faster this gyro turns the greater its corrective energy when swung laterally to varying degrees out of its normal fore-and-aft vertical plane of revolution. Thus, within a moderately small compass, an immense measure of counter-balancing energy can be aroused. It takes but a relatively small amount of power on the part of a precession engine to turn the gyro to right or left as far as need be. Of course when on duty, the big gyro is steadily spinning. The precession engine is called to service by two little gyros; one regulating the time of action and the other the degree of movement. These extremely sensitive sentinel gyros operate, by means of electrical connections, the throttle of the engine control and the manner of applying the steam to what we might call an ahead or a backing motion, in this case resulting in movements on the part of the gyro to right or left.

Influence of free water in the hold.—It will appear that there are essential differences between the case of free water present in large quantities in one or more compartments of the hold of a ship, and that of the comparatively small quantities of free water carried for steadying purposes in the specially constructed closed chambers. Common experience proves that the presence of large quantities of free water in the hold of a ship affects her rolling, is always objectionable, and may be dangerous. The transference of the water from side to side when the depth is considerable may be very rapid, and it will be obvious that the period of oscillation may be sensibly affected, while heavy blows may be delivered on decks, bulkheads and other portions of the structure. Considerable damage has been done in some cases where water ballast has been carried in large tank compartments of considerable depth and

where the surface has been left free either by leakage or by failure to fill the compartments.

Fundamental conditions of trochoidal theory.—Before considering the motion of a ship at sea among waves it is important to study something of the character of deep-sea waves. Many and divers attempts have been made to construct a mathematical theory of wave-motion and thence to deduce the probable behavior of ships at sea. It is now generally agreed that the modern, or trochoidal, theory of wave-motion fairly represents the phenomena presented, and without going into any discussion of the earlier theories, it is proposed in this chapter to explain the main features of this trochoidal theory for deep-sea waves.

According to this theory a single, or independent, series of waves is regarded as traversing an ocean of unlimited extent, where the depth, in proportion to the wave dimensions, is so great as to be virtually unlimited also. The bottom is supposed to be so deep down that no disturbance produced by the passage of waves can reach it, and the regular succession of waves requires the absence of boundaries to the space traversed. It is not supposed, however, that an ordinary seaway consists of such a regular single series of waves, though sometimes the conditions assumed are fulfilled; but more frequently two or more series of waves exist simultaneously, over-riding one another or perhaps moving in different directions, causing a confused sea. But in what follows it will be understood that, unless the contrary is stated, we are dealing with the primary case of a single series of deep-sea waves.

A few definitions must now be given of terms that will be frequently used.

The *length* of a wave is its measurement in feet from crest to crest or hollow to hollow.

The *height* of a wave is the vertical distance in feet from hollow to crest.

The *period* of a wave is the time in seconds its crest or hollow occupies in traversing a distance equal to the wave length; or the time which elapses between the passage past a stationary point of successive wave crests or hollows. If an observer proceeds in the

direction in which the waves are advancing the period of the waves will appear to be longer than it really is; travelling in a direction opposite to that of the wave advance likewise leads to an *apparent period* shorter than the real period. Similarly, proceeding in any oblique direction affects the apparent period; retreating obliquely from the waves *increases*, and advancing obliquely towards them *diminishes*, the apparent, as compared with the real, period.

The *velocity* of a wave in feet per second will, of course, be the quotient of the length divided by the period, and would commonly be determined by noting the speed of advance of the wave crest.

It is important to note that, when speaking of the *advance* or *speed* of a wave, it is only the *wave form* which advances and not the water composing the wave. This may be seen by watching the behavior of a piece of wood floating amongst waves; it is seen that, instead of being swept away as it must be if the particles of water on which it is borne had a motion of advance, and as it would be on a tideway where the particles of water do move onward, it simply moves backward and forward about a fixed mean position. Such a motion of wave form may be illustrated by securing one end of a rope and giving a rapid up-and-down motion to the other end; a wave form will travel from one end to the other, but it is evident that the particles composing the wave have not so travelled.

Orbital motion of particles and advance of wave form.—Accepting the condition that the profile of an ocean wave is a trochoid, the motion of the particles of water in the wave requires to be noticed, and it is here the explanation is found of the rapid advance of the wave form, while individual particles have little or no advance. The trochoidal theory teaches that every particle revolves with uniform speed in a circular orbit (situated in a vertical plane which is perpendicular to the wave ridge), and completes a revolution during the period in which the wave advances through its own length. In Fig. 50, suppose *P, P, P,* etc., to be particles on the upper surface, their orbits being the equal circles shown; then, for this position of the wave, the radii of the orbits are indicated

by *OP, OP,* etc. The arrow below the wave profile indicates that it is advancing from right to left; the short arrows on the circular orbits show that at the wave crest the particle is moving in the same direction as the wave is advancing, while at the hollow the particle is moving in the opposite direction.

For these surface particles the diameter of the orbit equals the height of the wave. Now suppose all the tracing arms, *OP, OP,* etc., to turn through the equal angles *POp, POp,* etc.; then the points *p, p,* etc., must be corresponding positions of particles on the surface formerly situated at *P, P,* etc. The curve drawn through *p, p,* etc., will be a trochoid identical in form with *P, P,* etc., only it will have its crest and hollow further to the left; and this is a motion of advance in the wave form produced by a simple

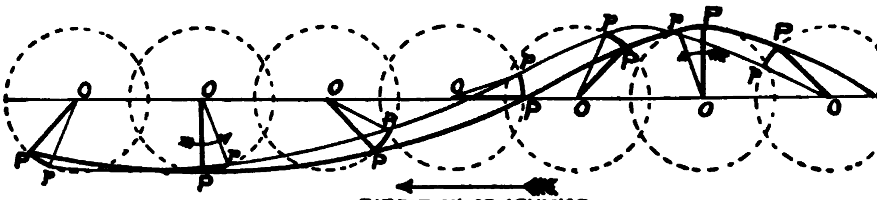


FIG. 50.

revolution of the tracing arms and particles (*P*). The motion of particles in the direction of advance is limited by the diameter of their orbits, and they sway to and fro about the centers of the orbits.

One other point respecting the orbital motion of the particles is noteworthy. This motion may be regarded at every instant as the resultant of two motions—one vertical, the other horizontal—except in four positions, viz.: (1) when the particle is on the wave crest; (2) when it is in the wave hollow; (3) when it is at mid-height on one side of its orbit; (4) when it is at the corresponding position on the other side. At the crest or hollow the particle instantaneously moves horizontally, and has no vertical motion; at mid-height it moves vertically and has no horizontal motion. Its maximum horizontal velocity will be at the crest or

hollow; its maximum vertical velocity at mid-height. Hence uniform motion along the circular orbits is accompanied by ac-

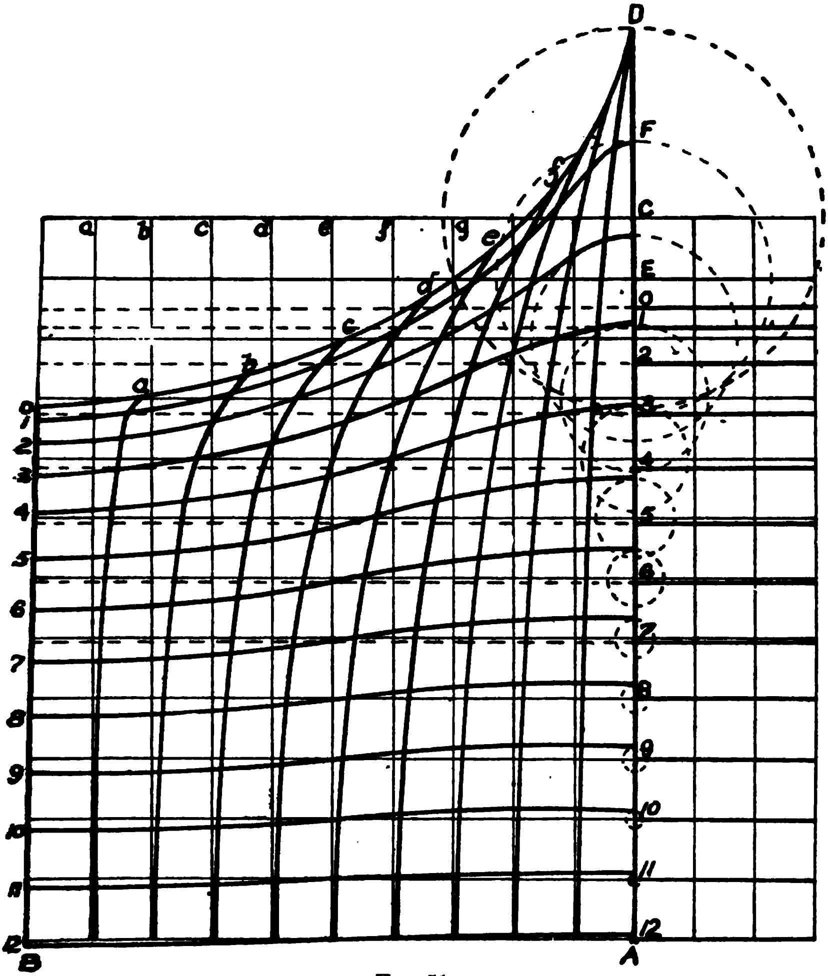


FIG. 51.

celerations and retardations of the component velocities in the horizontal and vertical directions.

Internal structure of wave.—The particles which lie upon the

upper surface of the wave are situated in the level surface of the wave when at rest. The disturbance caused by the passage of the wave must extend far below the surface, affecting a great mass of water. But at some depth, supposing the depth of the sea is very great, the disturbance will have practically ceased; that is to say, still, undisturbed water may be conceived as underlying the water forming the wave. Reckoning downward from the surface, the extent of the disturbance must decrease according to some law. The trochoidal theory expresses the law of decrease, and enables the whole of the internal structure of a wave to be illustrated in the manner shown in Fig. 51. On the right-hand side of the line AD the horizontal lines marked 0, 1, 2, 3, etc., show the positions in still water of a series of particles which during the wave transit assume the trochoidal forms numbered respectively 0, 1, 2, 3, etc., to the left of AD. For still water every unit of area in the same horizontal plane has to sustain the same pressure; hence a horizontal plane is termed a surface or subsurface of "equal pressure" when the water is at rest.

As the wave passes, the trochoidal surface corresponding to that horizontal plane will continue to be a subsurface of equal pressure; and the particles lying between any two planes (say 6 and 7) in still water will, in the wave, be found lying between the corresponding trochoidal surfaces (6 and 7). In Fig. 51, it will be noticed that the level of the still-water surface (0) is supposed changed to a *cycloidal* wave (0); this is the limiting height the wave could reach without breaking. The half-length of the wave (AB) being called L, the radius (CD) of the orbits of the surface particles will be given by the equation—

$$CD = R = \frac{L}{\pi}, \text{ or } \frac{7}{22} L \text{ (nearly)}.$$

Decrease of downward disturbance.—All the trochoidal surfaces have the same length as the cycloidal surface, and they are generated by the motion of a rolling circle of radius R; but their tracing arms—measuring half the heights from hollow to crest—rapidly decrease with the depth, the trochoids becoming flatter

and flatter in consequence. The crests and hollows of all the subsurfaces are vertically below the crest and hollow of the upper wave profile. The heights of these subsurfaces diminish in a geometrical progression as the depth increases in arithmetical progression; and the following approximate rule is very nearly correct. The orbits and velocities of the particles of water are diminished by *one-half,* for each additional depth below the mid-height of the surface wave equal to *one-ninth* of a wave length. For example—

Depths in fractions of a wave length below the mid-height of the surface wave.	$0, \frac{1}{9}, \frac{2}{9}, \frac{3}{9}, \frac{4}{9}$, etc.
Proportionate velocities and diameters.	$1, \frac{1}{2}, \frac{1}{4}, \frac{1}{8}, \frac{1}{16}$, etc.

Take an ocean storm-wave 600 feet long and 40 feet high from hollow to crest: at a depth of 200 feet below the surface ($\frac{3}{9}$ of length), the subsurface trochoid would have a height of about 5 feet; at a depth of 400 feet ($\frac{6}{9}$ of length), the height of the trochoid—measuring the diameter of the orbits of the particles there—would be about 7 or 8 inches only; and the curvature would be practically insensible on the length of 600 feet. This rule is sufficient for practical purposes, and we need not give the exact exponential formula expressing the variation in the radii of the orbits with the depths.

Displacement of vertical columns of particles.—Columns of particles which are vertical in still water become curved during the wave passage. In Fig. 51, a series of such vertical lines is drawn; during the wave transit these lines assume the positions shown by the heavy lines curving towards the wave crest at their upper ends, but still continuing to enclose between any two the same particles as were enclosed by the two corresponding lines in still water. The rectangular spaces enclosed by these vertical lines and the level lines are changed during the motion into rhomboidal-shaped figures, but remain unchanged in area.

Variation of direction and intensity of fluid pressure.—We now come to the consideration of the direction and intensity of the resultant fluid pressure in a wave, which must differ greatly from

those for still water. Each particle in a wave moving at uniform speed in a circular orbit will be subject to the action of centrifugal force as well as the force of gravity; and the resultant of these two forces must be found in order to determine the direction and intensity of the pressure on that particle. This may be done by a simple diagram of forces as shown in Fig. 52 for a surface particle. Let BED be the orbit of the particle; A its center; and B the position of the particle in its orbit at any time. Join the center of the orbit A with B; then the centrifugal force acts along the radius AB and the length AB may be taken to represent its magnitude. Through A draw AC vertically, and make it equal to the radius (R) of the rolling circle; then it is known that AC will represent the force of gravity on the same scale as AB represents centrifugal force. Join BC, and it will represent in magnitude and direction the resultant of the two forces acting on the particle.

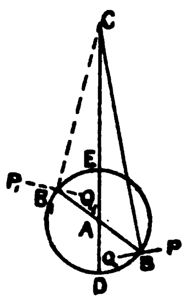


FIG. 52.

Now it is an established property of a fluid that its free surface will place itself at right angles to the resultant force impressed upon it. In Fig. 52, the resultant pressure shown by BC must be normal to that part of the trochoidal surface PQ where the particle B is situated. Similarly, for the position B_1, CB_1 will represent the resultant force; P_1Q_1 drawn perpendicularly to CB_1 being a tangent to the trochoid at B_1. Conversely, for any point on any trochoidal surface in a wave, the direction of the fluid pressure must lie along the *normal* to the surface at that point. At the wave hollow the fluid pressure acts along a vertical line; and as its point of application proceeds along the curve its direction becomes more and more inclined to the vertical until it reaches a maximum inclination at the point of inflection of the trochoid; thence onwards towards the crest the inclination of the normal pressure is constantly decreasing until at the crest it is once more vertical. If a small raft floats on the wave (as shown in Fig. 53), it will at every instant place its mast in the direction of the resultant fluid pressure. These motions of the

direction of the normal to the trochoid may be compared with those of a pendulum, performing an oscillation from an angle equal to the maximum inclination of the normal on one side of the vertical to an equal angle on the other side, and completing a single swing during a period equal to half the wave period.

Maximum slope of wave.—The maximum slope of the wave to the horizon occurs at a point somewhat nearer the crest than the hollow, but no great error is assumed in supposing it to be at mid-height in ocean waves of common occurrence where the radius of the tracing arm (or half-height of the wave) is about one-twentieth

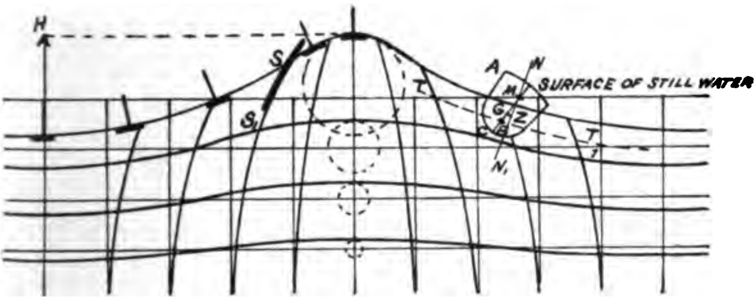


FIG. 53.

of the length. For this maximum slope, we have—

$$\text{Sine of angle} = \frac{\text{radius of tracing circle}}{\text{radius of rolling circle}}$$

$$= \frac{\text{half-height of wave}}{\text{half-length of wave} \div \pi}$$

$$= \pi \times \frac{\text{height of wave}}{\text{length of wave}}.$$

The angle of slope for waves of ordinary steepness will be small and the circular measure of the angle may be substituted for the sine, so we may write—

$$\text{Maximum slope in degrees} = 180° \times \frac{\text{height of wave}}{\text{length of wave}}.$$

Take, as an example, a wave 360 feet long and 14 feet high—

$$\text{Maximum slope} = 180° \times \tfrac{14}{360} = 7°.$$

The variation in the direction of the normal is in this case similar to an oscillation of a pendulum swinging 7 degrees on either side of the vertical once in every half-period of the wave.

Motions of a loaded pole.—Instead of the raft in Fig. 53, if the motions of a loaded pole on end (such as SS_1) be traced, it will be found that it tends to follow the original vertical lines and to roll always toward the crest as they do. Here again the motion partakes of the nature of an oscillation of fixed range performed in half the wave period, the pole being upright at the hollow and crest.

A ship differs from both the raft and the pole, for she has lateral and vertical extension into the subsurfaces of the wave, and cannot be considered to follow either the motion of the surface particles like the raft or of an original vertical line of particles like the pole.

Formulae for dimensions and speed of waves.—The trochoidal theory connects the periods and speeds of waves with their lengths alone and fixes the limiting ratio of height to length in a cycloidal wave. The principal formulae for lengths, speeds, and periods for trochoidal waves are as follows:

I. Length of wave (in feet) =

$$\frac{g\,T^2}{2\,\pi} = 5.123 \times \text{square of period (in secs.)}$$
$$= 5\tfrac{1}{8} \times \text{square of period (nearly).}$$

II. Speed of wave (in feet per sec.)

$$= 5.123 \times \text{period} = \sqrt{5.123 \times \text{length}}$$
$$= 2\tfrac{1}{4}\sqrt{\text{length}} \text{ (nearly).}$$

III. Speed of wave (in knots per hour) = 3 × period (roughly).

IV. Period (in seconds) $= \sqrt{\dfrac{\text{length}}{5.123}} = \dfrac{4}{9}\sqrt{\text{length}}$ (nearly).

V. Orbital velocity of particles on surface = speed of wave

$$\times \frac{3.1416 \times \text{height of wave}}{\text{length of wave}} = 7\tfrac{1}{9} \times \frac{\text{height of wave}}{\sqrt{\text{length of wave}}} \text{ (nearly).}$$

To illustrate these formulae, take a wave 400 feet long and 15 feet high. For it we obtain—

$$\text{Period} = \tfrac{4}{9}\sqrt{400} = 8\tfrac{8}{9} \text{ seconds.}$$

$$\text{Speed} = \tfrac{9}{4}\sqrt{400} = 45 \text{ feet per second.}$$

$$= 3 \times 8\tfrac{8}{9} = 26\tfrac{2}{3} \text{ knots per hour.}$$

$$\left.\begin{array}{l}\text{Orbital velocity of}\\ \text{surface particles}\end{array}\right\} = 7\tfrac{1}{9} \times \frac{15}{\sqrt{400}} = 5\tfrac{1}{3} \text{ feet per second.}$$

It will be remarked that the orbital velocity of the particles is very small when compared with the speed of advance; and this is always the case. In Formula V, if we substitute, as an average ratio for ocean waves of large size,

$$\text{Height} = \tfrac{1}{20} \times \text{length},$$

the expression becomes—

$$\left.\begin{array}{l}\text{Orbital velocity of}\\ \text{surface particles}\end{array}\right\} = 7\tfrac{1}{9} \times \frac{\tfrac{1}{20} \times \text{length}}{\sqrt{\text{length}}} = 0.355\sqrt{\text{length}}.$$

Comparing this with Formula II for speed of advance it will be seen that the latter will be between six and seven times the orbital velocity.

As a mathematical theory, that for trochoidal waves is complete and satisfactory, under the conditions upon which it is based. Sea-water is not a *perfect fluid* such as the theory contemplates; in it there exists a certain amount of viscosity, and the particles must experience resistance in changing their relative positions. But there is every reason to believe that the theory closely approximates to the phenomena of deep-sea waves.

Observations of lengths of waves.—From a scientific point of view, and as a test of the trochoidal theory, the observations made when a ship falls in with a series of approximately regular waves are most valuable. More frequently observations have to be conducted in a confused sea, successive waves differing from one another in lengths, heights, and periods, and occasional waves occurring of exceptional size as compared with their neighbors; but supposing a single series of waves to be encountered, the *lengths* and *periods* of successive waves can be easily determined if the

speed of the ship and her course relatively to the line of advance of the waves are known. The method adopted will be briefly described.

Two observers (*A* and *B*, Fig. 54) are stationed as far apart as possible at a known longitudinal distance from one another. At each station a pair of battens is erected so as to define, when used as sights, a pair of parallel lines at right angles to the ship's keel. The observers at both stations note the instant of time when a

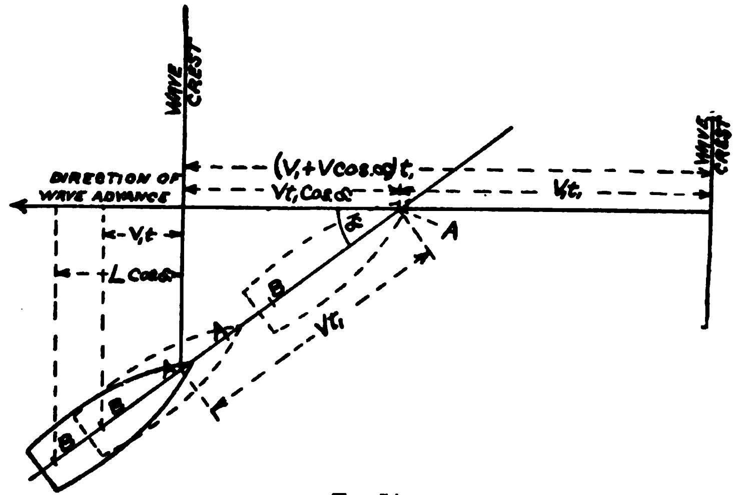


FIG. 54.

wave crest crosses their lines of sight; they also note how long an interval elapses before the next wave crosses their lines. Comparing their records, they determine (1) the time (say t seconds) occupied by the wave crest in passing over the length (L feet) between their stations; (2) the time (say t_1 seconds) elapsing between the passage of the first and second crest across either line of sight: this time is termed the "apparent period" of the waves. Suppose the ship to be advancing at a speed of V feet per second *towards* the waves, her course making an angle of α degrees with that course which would place her exactly end-on to the waves.

Then expressing the facts algebraically—

$$\text{Apparent speed of wave (feet per second)} = \frac{L}{t}.$$

$$\text{Real speed of wave (feet per second)} = V_1 = \left(\frac{L}{t} - V\right)\cos a.$$

$$\text{Real length of wave (feet)} = (V_1 + V\cos a)\, t_1 = L\cos a \,.\, \frac{t_1}{t}.$$

$$\text{Period of wave} = \frac{L\cos a}{V_1} \,.\, \frac{t_1}{t} = \frac{L \,.\, t_1}{L - Vt}.$$

If the ship is steaming *away* from the waves on the same course at the same speed it is necessary to change the sign of V in the foregoing equations.

From the foregoing remarks it will be obvious that the simplest method of observing the lengths and periods of waves can be applied when a ship is placed end-on to the waves and is stationary. The true period and true speed of the waves can then be obtained by direct observation, and the lengths estimated.

When ships are sailing in company, a good estimate of the lengths of waves may be made by comparing the length of a ship with the distance from crest to crest of successive waves. Care must be taken, of course, to note the angle which the keel of the ship used as a measure of length makes with the line of advance of the waves; otherwise the apparent length of the wave may considerably exceed the true length.

Another method of measuring wave lengths consists in towing a log-line astern of a ship, and noting the length of line when a buoy attached to the after end floats on the crest next abaft that on which the stern of the ship momentarily floats. For its successful application a ship should be placed end-on to the waves, or allowance must be made for the angle the log-line makes with the direction of the ship's course.

Observations of heights of waves.—Wave heights are, in most cases, readily measured by the following simple method: When the ship is in the trough of the sea, and for an instant upright, the observer takes up a position such that successive average wave ridges, as viewed by him from the trough, just reach the line of

the horizon without obscuring it. The height of his eye above water correctly measures the wave height. In making such observations it is desirable to select a position nearly amidships, so that the influence of pitching and 'scending may be diminished as much as possible. If it becomes necessary to take stations near the bow or stern, allowance must be made, in estimating the height of the eye above water, for deeper immersion which may be caused at the instant by pitching or 'scending. Due allowance must also be made for changes of level occasioned by rolling or heeling, as well as for the fact that when a ship end-on to the waves is in the middle of the trough the curvature of the wave hollow gives extra immersion to her ends, while the water surface amidships is somewhat below her natural water-line. To measure very high waves the observers may have to ascend the rigging; while for waves of less height a station on one of the decks may suffice, or some temporary expedient devised to place the observer near the water-level.

Cause of unintentional exaggeration in the estimate of wave heights.—An explanation of the cause of unintentional exaggeration in the estimate of wave heights is deserving of notice here. It will at once suggest itself when the variation in the direction of the normal to the wave slope is taken into account. To an observer standing on the deck of a ship which is rolling amongst waves, nothing is more difficult than to determine the true vertical direction along which the height of the wave must be measured. If he stands on the raft shown in Fig. 55, he will, like it, be affected by the wave motion; and the *apparent* vertical at any instant will be coincident with the mast of the raft and normal to the wave slope. He will therefore suppose himself to be looking horizontally when he is really looking down along a line parallel to the tangent to the wave slope at that point, which may be considerably inclined to the horizon. Suppose *TT*, Fig. 55, to represent this line for any position; then the apparent height of the waves to an observer will be *HT*, which is much greater than the true height. If the observer stands on the deck of a ship the conditions will be similar; the normal to what is termed the "effective wave slope" determines the apparent vertical at any instant; and the only easy way of de-

termining the true horizontal direction is by making an observation of the horizon as described above. The extent of the possible error thus introduced will be seen from an example. Take a wave 250 feet long and 13 feet high; its maximum slope to the horizontal is about 9 degrees. Suppose a ship to be at the mid-height between hollow and crest, and the observer to be watching the crest of the next wave; standing about the water level, the wave height will be seen to be about 30 feet instead of 13 feet. The steeper the slope of the waves, the greater liability is there to serious errors in estimates of heights, unless proper means are taken to determine the true horizontal and vertical directions. In some cases the apparent height would be about three times the real height.

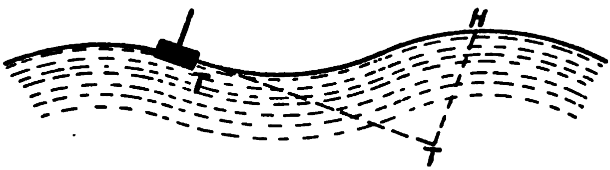


FIG. 55.

Character of oscillations in a seaway.—We have discussed the condition of a ship oscillating in still water and the phenomena of wave motion in the deep sea, subjects of which we must have a clear understanding before taking up the motions of a ship in a seaway, for at sea her motions are influenced by the stability, her inertia, by the variations in the direction and intensity of the fluid pressure due to wave motion and by the fluid resistance all in combination.

The motions of a ship in a seaway are of three principal kinds: the first and second being, like those in still water, the transverse oscillations of rolling and the longitudinal oscillations of pitching and 'scending; the third kind is known as "heaving" oscillations, which are more or less considerable vertical oscillations impressed upon a ship by the forces accompanying the vertical component of the orbital motions of particles of the wave structure. The rolling motions, having by far the most important bearing upon safety and good behavior, will be considered most particularly. Pitch-

ing and 'scending may become violent and objectionable in some ships, but this is not commonly the case nor so difficult of correction as heavy rolling, and only a brief discussion of them, and of the "heaving" oscillations, will be necessary, which will follow the remarks on rolling.

The governing conditions of the behavior of a ship among waves are twofold: (1) The ratio which the period of the still-water oscillations (or "natural period") of the ship bears to the period of the waves amongst which she is rolling. (2) The magnitude of the effect of fluid resistance. Both the natural period and the means of estimating the magnitude of the fluid resistance for any ship may be obtained from experiments made in still water, as previously explained.

It is most convenient to deal separately with these conditions, first illustrating the causes which make the ratio of the periods so important, and in doing so leaving resistance out of account; afterwards illustrating the effect of resistance in limiting the range of oscillation. In practice the two conditions, of course, act concurrently; but the hypothetical separation here made will probably enable each to be better understood.

Effect of waves in producing rolling.—Suppose a ship lying broadside-on to the waves to be upright and at rest when the first wave hollow reaches her; at that instant the normal to the surface coincides with the vertical; and there is no tendency to disturb the ship. But a moment later, as the wave form passes on and brings the slope under the ship, the virtual upright towards which she tends to move, becomes inclined to the vertical. This inclination at once develops a righting moment tending to bring the masts into coincidence with the instantaneous position of the normal to the wave. Hence rolling motion begins, and the ship moves initially at a rate dependent upon her still-water period of oscillation. Simultaneously with her motion, the wave normal is shifting its direction at every instant, becoming more and more inclined to the vertical, until near the mid-height of the wave it reaches its maximum inclination, after which it gradually returns to the upright; the rate of this motion is dependent upon the period of the wave.

Importance of ratio of period of rolling to half-period of wave.—Whether the vessel will move quickly enough to overtake the normal or not, depends upon the ratio of her still-water period to the interval occupied by the normal in reaching its maximum inclination and returning to the upright again, which it accomplishes at the wave crest; this interval equals *one-half* the period of the wave. Hence it appears that the ratio of the period of the ship (for a simple roll) to the half-period of the wave must influence her rolling very considerably, even during the passage of a single wave, and still more is this true when a long series of waves moves past, as will be shown presently. It will also be obvious that the chief cause of the rolling of ships amongst waves is to be found in the constant changes in the direction of the fluid pressure accompanying wave motion.

Two extreme cases may be taken as simple illustrations. The first is that of a little raft having a natural period indefinitely small compared with the half-period of the wave. Her motions will consequently be so quick as compared with those of the wave normal that she will be able continually to keep her mast almost coincident with the normal and her deck parallel to the wave slope. Being upright at the hollow, she will have attained one extreme of roll at about the mid-height of the wave and be upright again at the crest. The period of this single roll will be half the wave period. As successive waves in the series pass under the raft, she will acquire no greater motion, but continue oscillating through a fixed arc and with unaltered period. The arc of oscillation will be double the maximum angle of wave slope.

The other extreme case is that of a small vessel having a natural period of oscillation which is very long compared to the wave period. If such a vessel were upright and at rest in the wave hollow she would be subjected to rolling tendencies similar to those of the raft owing to the successive inclinations of the wave normal—her instantaneous upright. But her long period would make her motion so slow as compared with that of the wave normal that, instead of keeping pace with the latter, the ship would be left far behind. In fact, the half-period of the wave during which the

normal completes an oscillation would be so short relatively to the period of the ship that, before she could have moved far, the wave normal would have passed through the maximum inclination it attains near the mid-height of the wave, and rather more than half-way between hollow and crest. From that point onwards to the crest it would be moving back towards the upright; and the effort of the ship to move towards it, and further away from the upright, would consequently gradually diminish. At the crest the normal is upright and the vessel but little inclined—and even then inclined in such direction that the variations of the normal on the second or back slope of the wave will tend to restore her to the upright. Hence it is seen that the passage of a wave under such a ship disturbs her but little, her deck remains nearly horizontal, and she is a much steadier gun-platform than the raft-like ship.

No ship actually conforms to the conditions of either of these extreme cases, nor can her rolling be unresisted as here assumed. Experience proves, however, that vessels having very short periods of oscillation in still water tend to acquire a fixed range of oscillation when they encounter large ocean waves, keeping their decks approximately parallel to the effective wave slopes. Actual observations also show that vessels having the longest periods of oscillations in still water are, as a rule, the steadiest amongst waves, keeping their decks approximately horizontal and rolling through very small arcs.

Fundamental assumptions for mathematical investigation of unresisted rolling.—We now come to a more particular analysis along mathematical lines of the unresisted rolling of ships among waves. The modern method of investigation makes the following assumptions in order to bring the problem within the scope of exact mathematical treatment:

(1) The ship is regarded as lying broadside-on to the waves with no sail set, and without any motion of progression in the direction of the wave advance; in other words, she is supposed to be rolling passively in the trough of the sea.

(2) The waves to which she is exposed are supposed to form a regular independent series, successive waves having the same dimensions and periods.

(3) The waves are supposed to be large as compared with the ship, so that at any instant she would rest in equilibrium with her masts coincident with the corresponding normal to the "effective wave slope," which is commonly assumed to coincide with the upper surface of the wave.

(4) The righting moment of the ship at any instant is assumed to be proportional to the angle of inclination of her masts to the corresponding normal to the effective wave slope—the virtual upright.

(5) The variations of the apparent weight are supposed to be so small, when compared with the actual weight, that they may be neglected, except in very special cases.

(6) The effects of fluid resistance are considered separately, and in the mathematical investigation the motion is supposed to be unresisted and isochronous.

Upon the basis of these assumptions a rather complex dynamical equation is formed which furnishes an expression for the angle of inclination of the ship to the vertical at any instant in terms of her own natural period, the wave period, the ratio of the height to the length of the wave, and certain other known quantities. Assuming certain ratios of the period of the ship to the wave period, it is possible from the equation to deduce their comparative effect upon the rolling of the ship; or, assuming certain values for the steepness of the waves, to deduce the consequent rolling as time elapses and a continuous series of waves passes the ship. In fact, the general equation gives the means of tracing out the unresisted rolling of a ship for an unlimited time, under chosen conditions of wave form and period. A few of the more important cases will be briefly discussed.

Rolling amongst waves of synchronizing periods.—The first case to be considered is that in which the natural period of the ship for a single roll equals the half-period of the wave. It is a matter of common experience that if a pendulum receive successive

impulses, keeping time (or "synchronizing") with its period, even if these impulses, individually, have a very small effect, they will eventually impress a very considerable oscillation upon the pendulum. When a similar synchronism occurs between the wave impulse and the period of the ship, the passage of each wave tends to add to the range of oscillation, and were it not that the fluid resistance puts a practical limit to the range of oscillation, she would finally capsize. Suppose a vessel to be broadside-on in the wave hollow when the extremity of her roll is reached, say to starboard, the waves advancing from starboard to port. Then the natural tendency of the ship, apart from any wave impulse, is to return to the upright in a time equal to one-half her period, which by our hypothesis will be equal to the time occupied by the passage of one-fourth of the wave length. In other words, the ship would be upright midway between hollow and crest of the wave about where its maximum slope occurs. Now at each instant of this return roll towards the upright the inclination of the wave normal, fixing the direction of the resultant fluid pressure, is such as to make the angle of inclination of the masts to it greater than their inclination to the true vertical; that is to say, the inclination of the wave normal at each instant virtually causes an increase of the righting moment. Consequently, when the vessel reaches the upright position at the mid-height of the wave, she has by the action of the wave acquired a greater velocity than she would have had if oscillating from the same initial inclination in still water. She therefore tends to reach a greater inclination to port than that from which she started to starboard; and this tendency is increased by the variation in direction of the wave normal between the mid-height and crest—that part of the wave which is passing the ship during the period occupied by the second half of her roll—and since the ship, during the second half of the roll, inclines her masts away from the wave crest, with the angle between her masts and the wave normal constantly less than they make with the vertical, the effect is to make the righting moment less at every instant during the second half of the roll than it would have been in still water. For unresisted rolling, it is the work done in overcoming

the resistance of the righting couple which extinguishes the motion away from the vertical. On the wave, therefore, the vessel will go further to the other side of the vertical from that on which she starts than she would do in still water, for two reasons: (1) she will acquire a greater velocity before she reaches the upright; (2) she will experience a less check from the righting couple after passing the upright.

Variation of period of rolling due to increase of arc of oscillation.—More or less close approximation to this critical condition will give rise to more or less heavy rolling; but it is a noteworthy fact that, even where the natural period of the ship for small oscillations equals the half-period of the wave, and may thus induce heavy rolling, the synchronism will almost always be disturbed as the magnitude of the oscillations increases; the period of the ship will be somewhat lengthened, and thus the further increments of oscillation may be made to fall within certain limits lying within the range of stability of the ship. The angles of swing of ships are rarely so large as to make the increase of period great proportionately, but yet the increase may be sufficient to add sensibly to the safety of the ship when she is exposed to the action of waves having a period double her own period for small oscillations; although it is by the action of fluid resistance that the capsizing of a ship so circumstanced is chiefly prevented.

The effects of synchronism, which in theory is the worst condition for a ship to be subjected to, may often be produced by a ship steaming on a course oblique to the direction of wave advance when the apparent period of the wave becomes double the ship's natural period of oscillation; and here it is worthy of notice that, so long as the ship is manageable, the officer in command can to a great extent influence her behavior by the judicious change of the course and speeed to produce an apparent period of the wave such that the ratio of the periods of the ship and wave is made conducive to better behavior.

Practical conclusions on unresisted rolling.—In concluding these remarks on the case of *unresisted* rolling among waves, and bearing in mind that the actual behavior of ships at sea is greatly in-

fluenced by fluid resistance, we may briefly summarize our conclusions as follows: (1) Heavy rolling is likely to result from equality or approximate equality of the period of a ship and the half-period of the waves, even when the waves are very long compared to their height. (2) The best possible means, apart from increase in the fluid resistance, of securing steadiness in a seaway, is to give to a ship the longest possible natural period for her still-water oscillations. (3) Changes of course and speed of the ship relatively to the waves affect the relation between the periods and may either destroy or produce the critical condition of synchronism. (4) Vessels having very quick periods, say 3 seconds or less for a single roll, fare better among ordinary large storm waves than those having periods of 4 to 6 seconds (which approximate very closely to the half-period of large storm waves), since the tendency in these very quick-moving vessels is to acquire a fixed oscillation, keeping their decks approximately parallel to the effective wave slope; though such a vessel would not be a steady gun-platform. (5) For small sea-going vessels, for which the still-water periods are made short by the smallness of their moment of inertia, and the necessity for retaining a sufficient amount of stiffness, the effective wave slope is very nearly the upper surface of the wave, and their range of oscillation among large waves is practically determined by the wave-slope; but amongst smaller waves, approaching the condition of synchronism, these small vessels are worse off than very broad vessels of equally short periods because the effective wave slope for the broad vessels is so much flatter.

Effect of fluid resistance on rolling among waves.—The deductions from the hypothetical case of *unresisted* rolling among waves can be regarded only as of a qualitative and not of a quantitative character. Although the *character* of the motion is well described by the deduction from the hypothetical case, its *extent* is not thus determined. The effect of resistance, and, in the case of isochronous rolling, change of period with increased arcs of oscillation, must be considered when exact measures of the range of oscillation are required as for the determination of the safety of ships. The problem therefore resolves itself into one of correcting the deduc-

tions from the hypothetical cases by the consideration of the effect of fluid resistance, and by allowing for departures from isochronism as rolling becomes heavier.

In accordance with the principles explained above, it is possible to ascertain the amount of resistance of a ship corresponding to any arc of oscillation. If a vessel rolls through a certain arc amongst waves, it appears reasonable to suppose that the effect of fluid resistance will be practically the same as that experienced by the ship when rolling through an equal arc in still water. The intrusion of the vessel into the wave, as previously remarked, must somewhat modify the internal molecular forces, and she must sustain certain reactions, but for practical purposes these may be disregarded. Resistance is always a retarding force; in still water it tends to extinguish oscillation; amongst waves it tends to limit the maximum range attained by the oscillating ships.

Influence of resistance in the critical case of synchronism.—This may be well seen in the critical case of synchronism; where a ship rolling unresistedly would have a definite addition made to her inclination by the passage of each wave. The wave impulse may be measured by the added oscillation; the dynamical stability corresponding to the increased range expressing the energy of the wave impulse. At first the oscillations are of such moderate extent that the angular velocity is small, and the wave impulse more than overcomes the effect of the resistance, and the rolling becomes heavier. As it becomes heavier, so does the angular velocity increase, and with it the resistance. At length, therefore, the resistance will have increased so much as to balance the increase of dynamical stability corresponding to the wave impulse; then the growth of oscillation ceases. As successive waves pass the ship after this result is attained, they each deliver their impulse as before, but their action is absorbed in counteracting the tendency of the resistance to retard and degrade the oscillations.

Steadying influence of bilge-keels.—The conclusion to be drawn then is that any means of increasing the fluid resistance to the rolling of a ship tends to limit her maximum oscillations among waves. Circumstances may and do arise in the designing of war-

ships which make it difficult, if not impossible, to associate requisite qualities with the long still-water period which theory and observation show to be favorable to steadiness; and in such cases bilge-keels are frequently fitted.

The form of the immersed part of a ship and the condition of her bottom also very considerably affect the aggregate resistance, both of these conditions being included in the determination of the co-efficient of resistance to rolling; but the form of a ship is planned by the naval architect mainly with reference to its stability, carrying power, and propulsion, the consideration of its resistance to rolling being a subordinate feature, and best effected by leaving the under-water form of the ship herself unaltered, and simply adding bilge-keels in cases where the size and inertia of the ship are such as to make them useful, and when the conditions of the service of the ship, the sizes of the docks she has to enter, or other circumstances permit their use.

Pitching and 'scending.—The longitudinal oscillations of pitching and 'scending experienced by ships among waves must now be briefly considered. In still water these longitudinal oscillations do not occur under the conditions of actual service; and it is difficult, even for experimental purposes, to establish such oscillations, because of the great longitudinal stability of ships. On this account we have little definite information respecting still-water periods for pitching, or the "co-efficients of resistance" for longitudinal oscillations.

The formula for the period of *unresisted* pitching may be expressed in the same form as that given before for the period of unresisted rolling, where m is, in this case, the longitudinal metacentric height, and k is the radius of gyration taken with reference to the transverse axis through the center of gravity. The effect of the great longitudinal height more than counterbalances the effect of the increased moment of inertia for longitudinal oscillations, whence it follows that the period for pitching is usually con-

siderably less than that for rolling, lying in many cases between one-half and two-thirds of the period for rolling.

The existence of waves supplies a disturbing force capable of setting up longitudinal oscillations, leading to disturbances of the conditions of equilibrium as they exist in still water, and to the creation of accelerating forces due to the excess or defect of buoyancy.

The chief causes influencing the pitching and 'scending of ships amongst waves will be seen to bear a close analogy to what has been said in this regard about rolling, and will not require further explanation in detail. They are: (1) the relative lengths of waves and ships; (2) the relation between the natural period (for longitudinal oscillations) of the ship and the apparent period of the waves, this apparent period being influenced by the course and speed of the ship as previously explained; (3) the form of the wave profile, *i. e,* its steepness; (4) the form of the ship, especially near the bow and stern, in the neighborhood of the still-water load-line, this form being influential in determining the amounts of the excesses or defects of buoyancy corresponding to the departure of the wave profile from coincidence with that line; (5) the longitudinal distribution of weights, determining the moment of inertia. In addition, fluid resistance exercises a most important influence in limiting the range of the oscillations. This resistance is governed by the form of the ship and particularly by that of the extremities, where parts lying above the still-water load-line are immersed more or less as the ship pitches and 'scends, and therefore contributes to the resistance.

Heaving oscillations.—In addition to the transverse and longitudinal oscillations above described, a ship floating amongst waves has impressed upon her more or less considerable vertical oscillations, "heaving" up and down as the waves pass her. Taking the extreme case of the small raft in Fig. 53, it will be seen that her center of gravity performs vertical oscillations of which the amplitude equals the wave height, and the period is the wave period. This is termed "passive heaving." A ship of large dimensions relatively to the waves obviously would not perform such large vertical

oscillations. The extent of these vertical movements would depend upon her position relative to the waves, her course and speed as affecting the apparent period of the waves, the form of the effective wave slope, and the under-water form of the ship.

Since, as we have seen above, the vertical and lateral extension of a ship into the wave structure has some influence on the effective wave slope, the movement of the center of gravity of a ship in passive heaving is considered as similar to that of a particle in the wave lying on the trochoidal surface passing through the center of buoyancy, when broadside-on to the waves. When end-on to the waves, it has been proposed to take the mean of the vertical motions in the effective wave slope which she covers; but when dealing with longitudinal oscillations this is not considered as of much practical value.

Speaking generally, it may be said that the vertical oscillations of a ship result from the operation of excesses or defects of buoyancy due primarily to the passage of the waves and their trochiodal forms, but actuated in many cases by the transverse and longitudinal oscillations. Heaving motions are favorable to seaworthiness and safety, since they make it less probable that waves will break on board. A ship so small as to practically accompany the vertical component of the wave-motion—riding "like a duck" —makes good weather. When ships are beam-on to the sea and roll but little, heaving motions of considerable extent may take place, and amongst large waves these motions may be nearly as great as those of surface particles. When ships are end-on to waves, although passive heaving may have a small amplitude, the effect of pitching and 'scending accompanying the vertical movement of the center of gravity of the ship may be considerably increased having an important bearing on the longitudinal bending moments.

It may be remarked, that in the actual behavior of ships at sea all of these different kinds of oscillations may be occurring simultaneously, and may mutually influence one another. Careful observations alone can decide upon their absolute values and

ordinarily rolling motions alone are considered worthy of observation.

Observations of rolling and pitching of ships.—Without attempting any extended discussion of the numerous methods of observing rolling motions of ships at sea, some of which involve the use of elaborate instruments, a few brief remarks will be made upon two methods employing such simple apparatus as is usually found on board ship or may be easily rigged.

These methods are (1) the use of pendulums in various forms of clinometers, these pendulums having periods of oscillation which are very short as compared with the periods of the ships; and (2)

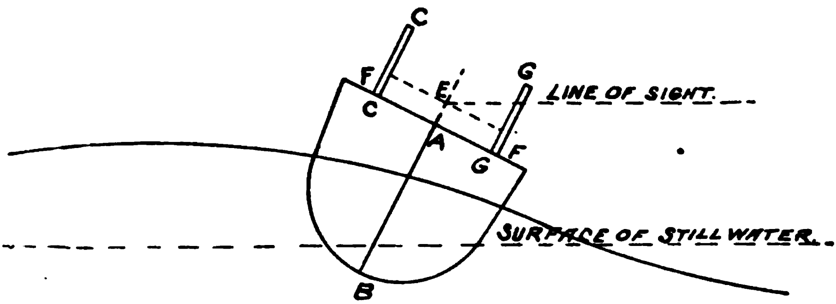


FIG. 56.

the use of sighting battens arranged so that the angle of inclination of the ship to the visible horizon may be directly observed.

Observations of rolling by use of battens.—The use of battens affords the simplest correct means of observing the oscillations of ships; they can be employed whenever the horizon can be sighted. The line of sight from the eye of an observer standing on the deck of a ship to the distant horizon remains practically horizontal during the motion of the ship. Consequently, if a certain position be chosen at which the eye of the observer will always be placed, when the ship is upright and at rest the horizontal line passing through that point is determined and marked in some way; this horizontal line can be used as a line of reference when the ship is rolling or pitching, and the angle it makes at any time with the line of sight will indicate the inclination of her masts to the vertical. In Fig.

56, the point E on the middle line marks the position of the eye of the observer, and at equal distances athwartships, two battens CC and GG are fixed so that when the ship is upright and at rest these battens are vertical, and at that time the line FEF will be horizontal. This may be termed the "zero-line"; and the points FF would be marked on the battens. Suppose the figure to represent the case of a ship rolling among waves; when she has reached the extreme of an oscillation to starboard, the angle GEF, whose tangent is given by $\frac{GF}{EF}$, measures the angle of inclination of the masts to the vertical. If the battens are placed longitudinally, instead of transversely, the angle of pitching may be similarly measured. It is a great practical convenience to have the battens graduated to a scale of angles so that an observer can at once read off and note down the angles of inclination in degrees. This is simply effected by marking vertical distances above F on the battens equal to the distance EF times the tangents of the successive angles.

CHAPTER IX.

STRENGTH.

A ship is subjected, in service, to certain stresses. These stresses may result in strains of two kinds:

(1) Structural strains, affecting the structure as a whole.

(2) Local strains, affecting only a certain part of the whole structure.

In considering structural strains, the whole ship is generally considered as a beam or girder. From his work in mechanics, the question of beam stresses and strains when the beam is supported in various manners, is familiar to the student; also the definition of neutral axis and the derivation and application of the formula

$$\frac{p}{y} = \frac{M}{I}.$$

Where, having assumed a section,

p = stress on any fiber,

y = distance of this fiber from neutral axis,

M = bending moment to which the beam is subjected at the section,

I = moment of inertia of the section of beam about its neutral axis.

In general, considering the section of a beam, the fibers of the section farthest away from the center or neutral axis contribute most to the strength of the beam.

In designing the structural features of a ship, this principle and the principle of beam stresses are kept in mind. Thus the main deck, or upper strength deck, and its adjacent structure, and keels and inner bottom structure, for a long ship, are generally of greater strength for a given displacement than in the case of a short ship, as M is greater.

For structural strength calculations in the U. S. Service, the ship is assumed poised on a wave—

(1) of the length of the ship $\times \frac{1}{20}$ its length in height, with crest at middle of length (Fig. 57); or,

(2) of the length of the ship $\times \frac{1}{20}$ its length in height, with the trough of wave at the middle of length (Fig. 58).

(1) results in the ends tending to droop, as the greatest support is in the middle, and such drooping is called "hogging."

(2) results in the middle tending to droop, the buoyancy being at the ends, and this change of shape is called "sagging."

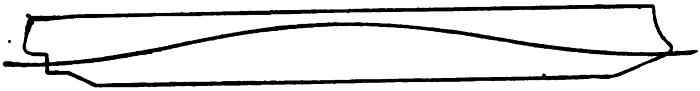


FIG. 57.

Condition (1) above is, for battleships and similar craft with heavy turrets and weights at ends, the most severe condition; (2), above, is probably worst for torpedo-craft where the principal weight is the propelling machinery amidships.

The choice of the two calculations to be made to determine the strength of the ship, should depend on type of ship, distribution of weight, and form of hull.

In well-constructed ships, these are only tendencies and no visible results occur. Should the structure not be strong enough,

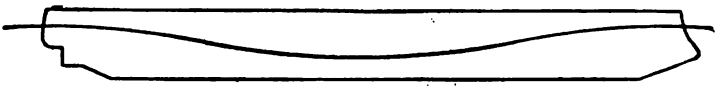


FIG. 58.

difficulty occurs. Instances are not wanting of where actual disruption has happened. Even in still water these tendencies exist in one form or another, owing to the supporting force of buoyancy differing from the corresponding weight to be supported at various points in the length of the ship. These tendencies are, however, much less than in a seaway.

The adoption of this standard calculation does not result in being able to obtain the exact stresses to which the ship is subjected, owing to the dynamical conditions present in actual service and other factors omitted from the calculations, but it permits a com-

parison between known and tried structures, and those to be designed.

Experiments with an actual ship structure, a British torpedo-boat, supported in dry dock in a manner so as to simulate the conditions afloat have been made and the strains measured with Stromeyer indicators show to a remarkable extent the accuracy of this system of calculation.

In special cases it has been necessary to employ special material of higher tensile strength than usual for the strength decks and keel structure.

The protective deck usually fitted in battleships and cruisers being located near the neutral axis, is poorly located for strength purposes, and contributes little to the structural strength of the ship as a whole, in proportion to its weight, but is necessary for the protection of machinery and magazines, and forms a secure platform from which to start upper structures, such as turret and gun foundations. In the latest type of U. S. battleship this deck being higher contributes considerably to the structural strength.

In the U. S. Service, all large vessels are framed on the longitudinal system, the keel or longitudinal center rib being continuous, as are various other fore and aft members out at the sides, called longitudinals, and the frames or transverse members forming the ribs of the ship, on which the shell plating is placed, are interrupted between these longitudinal members, or, as it is called in shipbuilding, *intercostal*. This system of framing is carried out from keel to protective deck, and fore and aft within the limits of the inner bottom, which, in the more recent ships of the U. S. Service, is carried as far forward and aft as the shape of the vessel will permit. Above the protective deck the transverse members are generally continuous. Forward and abaft the inner bottom, the transverse members are continuous on either side of the vertical keel and the longitudinals, except the vertical keel, scored out over them, or intercostal between them. This, by consideration, will be seen to be logical, as the value of M decreases towards the ends of the ship.

For torpedo-boats and small vessels having no inner bottoms, the shell plating being necessarily thin, the transverse members are generally continuous and closely spaced to support the plating, and the longitudinals intercostal.

Warships, as compared with merchant ships in general, show the following differences:

Warships have wider frame spacing, lighter scantling, *i. e.,* thickness of material, greater extent of inner bottom, longitudinal system of framing instead of transverse, and more water-tight subdivisions.

All the above are possible owing to different conditions of service, greater care in maintenance, and the fact that first cost of construction is not so vitally important as the results obtained.

The U. S. regulations for care and inspection of hulls and fittings will be quoted later.

It is important that there should be no point of discontinuity in the structure, *i. e.,* the strength should not change suddenly. For this reason, where any part of a fore and aft structure is to be ended, it has to be tapered down.

Sliding or expansion joints are sometimes fitted in superstructures owing to their being of light material and far from the neutral axis so that they may not form a part of the structural strength and so be torn apart by the stresses.

Transverse stresses.—The rolling of the ship will tend to rack the structure, and, to a certain extent, the same conditions apply as in considering fore and aft stresses; but the transverse bulkheads are so numerous and the general strength in this direction so great that these stresses need not be a matter of anxiety, except when in drydock, which will be treated of later.

Local strains.—All the above applies to the structure as a whole. There are certain local stresses and strains to be considered bearing on special parts of the structure:

The in and out working of the plating between frames, called *panting.* This is especially noticeable forward due to impact of ship with sea. Often additional stiffening is fitted here, or the armor is carried forward, or vertical and longitudinal ram plates

and breast hooks fitted to back up the same, accomplish the purpose desired.

Severe local strains occur under heavy weights, as turrets and barbettes, and where subjected to shock, as under gun foundations. These structures are specially designed, and are supported by beams, columns or stanchions, and bulkheads.

Engine and boiler foundations, windlass foundation, boat crane, masts, thrust blocks, and similar items require special structures.

Bulkheads require to be designed to withstand pressures due to adjacent compartments being filled with water. In the U. S. Service, actual tests are made of all bulkheads, under pressure, in building.

The propeller struts and ram require special framing, and the armor special backing to bring out its resisting qualities.

A number of these will be treated of in some detail later.

CHAPTER X.

RESISTANCE AND MODEL TANK.

One of the most important functions of the naval architect is the determination of the underwater form of the vessel and of the horsepower necessary to obtain a given speed for a vessel.

The question of resistance and propulsion on the admiralty coefficient basis is treated at some length in other parts of the midshipman's course, and, to prevent duplication, the methods there treated of will not be discussed here.

It should be noted, however, that the most modern method of obtaining the horsepower required, and the one now used by the U. S. Service, is the *model tank* method, where the resistance of a small model of the ship is determined by towing in a tank, and the resistance of the full-sized ship determined therefrom by means of Froude's Law.

A Brief Description of the Functions and Operation of an Experimental Model Basin.

The original and fundamental idea in the establishment of experimental basins, or, as they are otherwise called, "model tanks," was to assist in the determination of the resistance of ship-shaped forms at various speeds of propulsion, and thence the deduction of the power required to drive a given form at a given speed, and also the most desirable form for any given speed.

Their functions have been extended to include experiments with propellers, tending toward the solution of the problem of the best form, dimensions, and locations of propellers, and to include other experiments of kindred nature in connection with problems of ship construction and propulsion.

Originally, the underwater forms of vessels were determined by experience with full-sized ships, or by considering, by looks and touch, the shape of a small wooden model.

Some experiments on the resistances of various surfaces were made in the eighteenth century by several naval architects and others interested in the subject; notable among these was Colonel Beaufoy, the results of whose experiments were published in 1834.

In 1874, in a paper presented to the British Institution of Naval Architects, Mr. William Froude propounded what is now known as "Froude's Law," or the "Law of Comparison," which is a special application of the law of similitude, first propounded by Newton.

The whole usefulness of model-basin experiments is due to the truth of this law, which permits accurate and exhaustive experiments at reasonable cost, and the accurate determination of characteristics of a given model prior to building, which in turn permits ready determination of the horsepower necessary to give any required speed in the full-sized ship.

The law, which was deduced by Mr. Froude, with the aid of the British admiralty, from consideration of results of experiments with the British ship *Greyhound* and with models towed in the basin at Torquay, may be expressed in the following words:

Eliminating the resistance due to skin friction, if a ship be D times the dimensions of a model of similar form, and if at the speeds V_1, V_2, V_3, the measured resistances of the model are R_1, R_2, R_3, then for speeds $\sqrt{D}V_1$, $\sqrt{D}V_2$, $\sqrt{D}V_3$, of the ship, the resistances will be D^3R_1, D^3R_2, D^3R_3.

The speeds V_1, V_2, V_3 for the model and $\sqrt{D}V_1$, $\sqrt{D}V_2$, $\sqrt{D}V_3$ for the ship are termed corresponding speeds.

It was early found that the skin friction did not follow this law.

The three elements of ship's resistance have been determined to be, (1) skin friction, (2) eddy resistance, (3) wave making resistance.

The total resistance, minus the skin friction, is termed the residuary resistance.

The skin friction of a ship has been found by many experiments to be practically the same as that of a plane surface of the same nature, area, and length in the direction of motion as the curved wetted surface of the ship.

The skin resistance of a ship may then be expressed as a formula:

$$R_s = fSV^n.$$

where R_s = skin resistance.
S = wetted surface in sq. ft.
V = the speed in knots.
f, n = semi-constants changing somewhat with the nature and dimensions of the surface and determined by experiment only.

Tables of these constants, as separately determined by Mr. R. E. Froude and Dr. Tideman, are given in Taylor's "Speed and Power of Ships."

The original experimental basin, as stated, was developed by Mr. Froude and was located at Torquay, being established in the seventies. (The British experimental station has since been removed to Haslar. See below.) Since that time a number of experimental stations have been established, both by private firms and by governments. A partial list of such stations follows:

EXPERIMENTAL MODEL STATIONS.

Date.	Location.	Length.	Breadth.	Draught.
1884	Leven Shipyard, Dumbarton	300	20	8.8
1886	Haslar	400	20	9.2
1889	Spezia	479	19.7	9.8
1900	North German Lloyd S. S. Co., Bremerhaven	538	19.7	10.0
1903	Charlottenburg	528	34.5	11.5
1904	John Brown & Co., Clydebank	490	32.0	10.0
1899	U. S. Government, Washington, D. C.	470	42.8	14.8
1905	University of Michigan, Ann Arbor	300	22	10
1907	French Government	528	32.8	14

All these vary in matters of constructional detail, but all aim at the same results, and the variations are due in most part to differences of local conditions or considerations of expense.

Probably one of the most complete is the U. S. Government basin located at the U. S. Navy Yard, Washington, D. C., and operated under the Bureau of Construction and Repair of the Navy. The design and installation of this basin was under the

direction of Naval Constructor D. W. Taylor, U. S. N., who has also been in charge of the experimental work since the opening of the basin in 1900.

The basin holds about a million gallons of water. It is filled from the city supply for Washington.

Before reaching the basin the water is treated with a small quantity of alum, which removes any mud present, and is then clarified by passing through a sand filter.

A small stream is kept constantly running through the filter to freshen the water after filling, and to make up for leakage and waste.

The basin can be pumped dry in about four hours by an electrically-driven centrifugal pump. Two other electrically-driven pumps are fitted, a four-inch centrifugal pump connected with troughs on each side of the basin just at the surface, by which the water can be "scummed," and a small plunger pump used for drainage and piped to take the water from inside or outside the basin as desired.

The building is heated by hot air. The temperature is generally kept slightly higher than is usual for an ordinary living or working room. Otherwise the operators of the traveling carriage are liable to discomfort from their constant motion to and fro through the damp air.

Steel troughs about 12 inches square in sections are located on each side and just below the usual working level of the water. They act as absorbers of wave disturbances and cause them to die away rapidly. In addition there is at one end of the basin a "wave-breaker," consisting of a large number of square strips of wood set vertically at varying distances apart. These, with the side troughs, result in reducing any wave motion set up by a run of a model into minute ripples by the time eddies and currents due to the passage of the model, have been dissipated. Without wave-breaking appliances, running trials at high speeds would be a long operation as long waits between runs would be necessary to allow the waves to subside.

The apparatus for measuring the resistance of models is carried on the traveling carriage which spans the basin as shown in Fig. 59. This carriage weighs about 70,000 pounds, and hence has sufficient inertia to resist sudden variations of speed.

The carriage is driven by four motors, one on each corner. The speed is controlled on the Ward-Leonard system. Current from an "exciter" generator at 110 volts keeps constant excitation in the field coils of the motors and current from the same exciter passes through the controlling rheostats on the carriage and also around the field coils of the main generator.

The main generator runs at constant speed controlled by a governor which limits variation of speed within 1½ per cent from no load to full load. The generator armature is in series with the motor armature, so that all the current developed at the generator passes through the motors, the voltage at the generators varying according to the amount of excitation of the generator fields which is controlled from the carriage.

The four motors are so arranged that they may be connected all in series, or two and two in series, the pairs being parallel.

The maximum generator voltage is 250, and as there are two generators which can be arranged in series, the maximum available voltage is 500. The motors are geared together, two and two across the carriage, and also geared down to the main driving wheels. In addition, the forward pair of motors has back gearing for low speeds. For many experiments one generator only is required, the motors being arranged all four in series for speeds ranging from ½ knot to about 6½ knots, and two and two in series parallel for speeds from 6½ knots to about 12½ knots.

The maximum speed at which the carriage can run is about 20 knots, developed in a run of about 200 feet.

With such a heavy mass moving at this speed in a confined space, very careful provision is required for stopping.

With the Ward-Leonard system a powerful electrical braking effect is obtained from the driving motors, through the back current generated when the exciter current around the generator fields is shut off or reversed. This enables the carriage to be

Naval Construction.—To follow Page 158.

FIG. 59.

stopped more rapidly than it is started. This method of stopping is not relied upon solely, since it fails if the circuit is broken either accidentally or by the automatic circuit breakers in case of an overload. This method also necessitates proper manipulation on the part of the person operating the carriage. At least one method of braking to stop the carriage in the minimum possible distance was desirable, independent of the electric current, and not requiring manipulation by the operator. Wheel brakes could not be used, as they would cause objectionable wear on the wheels of the springless carriage, and would stop it no more rapidly than the electric brake supplied by the Ward-Leonard system (it may be noted that from time to time the wheels require truing up to insure accurate measurements). Friction brakes closed by hydraulic pressure were therefore fitted. These are fitted at the north end of the basin in the form of a pair of iron strips on each side, securely anchored at one end to the main walls of the building, and pressed together by hydraulic cylinders. They are 15/16 inch apart when the pressure is on and 1-1/6 inches apart when it is off, being pulled apart by springs when the pressure is released. A strip of iron about 1 inch thick and 12 feet long is securely bolted to each forward corner of the carriage, and is adjusted to enter without shock the space between the stationary strips, and by friction against them bring the carriage to rest. Hydraulic pressure is obtained from a small electric pressure pump, and an accumulator is fitted, through which the pressure can be varied from 100 pounds to 600 pounds per square inch. Two gauges at the south end of the basin indicate the pressure in the hydraulic cylinders, so that the operators may know before starting a run that the friction brake has pressure on. The strips are kept lubricated in order to avoid seizing or violent shock.

In addition to these, there is an emergency brake, which takes hold of the carriage if it should get through the friction brake without being arrested. This consists of a taper piston rod passing through a round hole in the cylinder head, which it gradually closes as it moves; the principle is the same as the hydraulic recoil brakes for heavy guns. The hydraulic cylinder is below the water

level when the basin is full, and when this is the case the emergency brake is always ready. The parts of this brake are bolted in place by fastenings which will be broken in case the brake comes into action, but up to the present time this has never happened.

Models.—Paraffine, which is largely used for models in experimental basins abroad, has many advantages, but cannot be used in Washington as it will not stand the summer temperature without too much softening.

As compared with paraffine as a material for the construction of models, white pine has the following advantages and disadvantages:

Advantages.—(1) Wood retains its shape better during changes in weather.

(2) Wood is many times stronger.

Disadvantages.—(1) Wood is harder and more expensive to fashion.

(2) Wooden models are harder to keep tight.

(3) Wooden models are harder to give a uniform surface.

The first and second objections have been overcome by the adoption of special machinery designed by Naval Constructor Taylor, and the third by using a special varnish to finish the models, which gives a surface practically uniform.

Owing to the greater strength of wood it is feasible to make models 20 feet long, and the sectional area of the basin is such that these models may be run with no greater interference from the size of the basin than 12-foot models in the smaller foreign basins.

The advantages of this size, as compared with the 12-foot size, in determining resistance, are great. It is found that for the 20-foot models of many U. S. naval vessels, the resistance at the speeds corresponding to the actual maximum speeds of the vessels, is below 40 pounds. With 12-foot models the resistances would have been below 9 pounds. A 20-foot model is 1/1728 the displacement of a 240-foot vessel, and 1/13,824 that of a 480-foot ship.

For a 12-foot model these figures are 1/8000 and 1/64,000, respectively.

With the large model, resistance is measured more easily to a given percentage of accuracy, and the gap between models and ships to be bridged by the Law of Comparison is not so great.

It is the usual practice at the U. S. model basin in the case of models of men-of-war to determine five resistance curves, each extending somewhat beyond the speed corresponding to the maximum speed of the vessel. These curves are as follows:

No. 1. With the model at a displacement corresponding to the designed normal displacement of the ship and at the designed trim of the ship.

No. 2. With the model as in No. 1, except the trim is changed four inches by the head.

No. 3. With the model as in No. 1, except the trim is changed four inches by the stern.

No. 4. With the model as in No. 1, except that it is 10 per cent lighter.

No. 5. With the model as in No. 1, except that it is 10 per cent heavier.

Fig. 60 shows these five curves for a model representing the *Yorktown*. The displacement of this vessel corresponding is 1680 tons and the designed trim 2 feet 1½ inches by the stern. The maximum speed of the *Yorktown*, when tried at 1680 tons, was 16.7 knots. The corresponding speed of the model is 4.93 knots. The curves of Fig. 60 are carried higher in proportion to the designed speed of the vessel than is necessary.

The speeds of 20-foot models corresponding to the maximum speeds of some of our battleships are given below:

Battleship.	Length.	Maximum.	Corresponding speed of 20-foot model.
Oregon class	348	16.8 trial	4.03
Iowa class	360	17.1 "	4.03
Kentucky and *Alabama* classes	368	17.1 "	3.99
Maine class	388	18	4.09
Georgia class	435	19	4.07

Fig. 59 shows the carriage in operation, towing a model of a battleship.

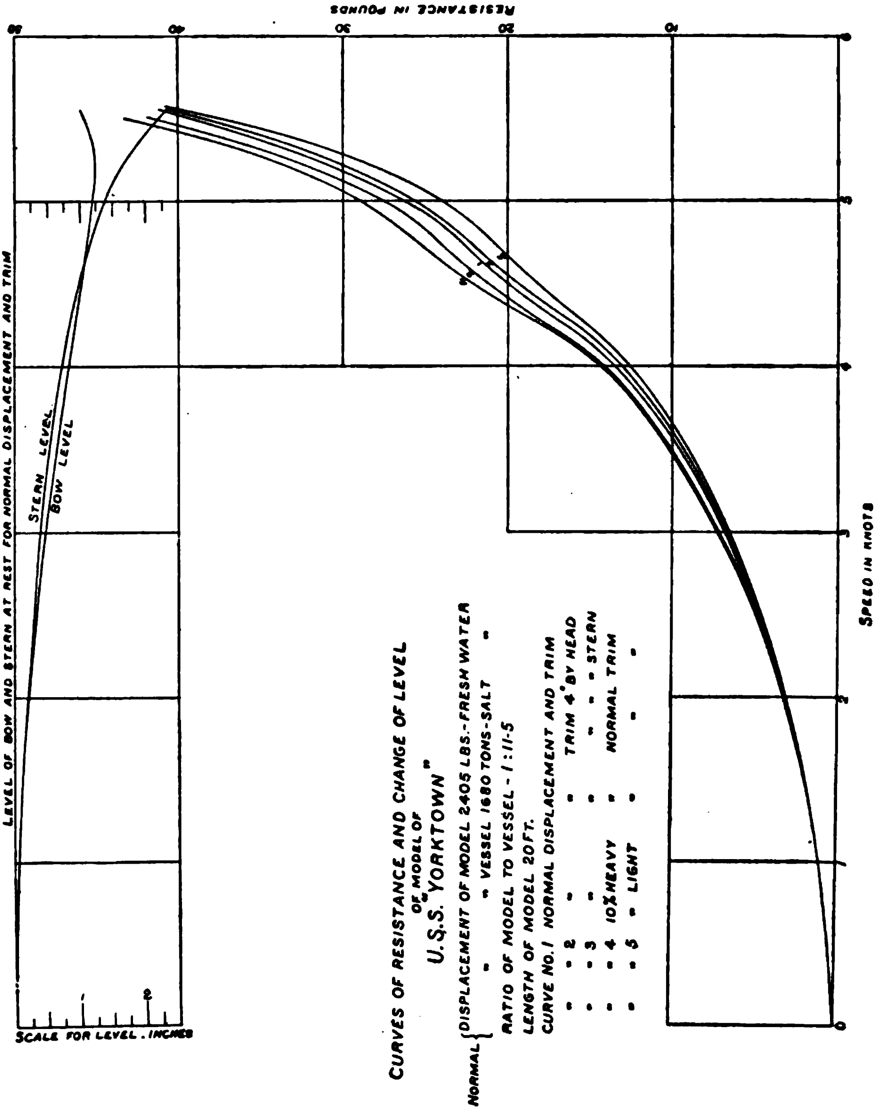
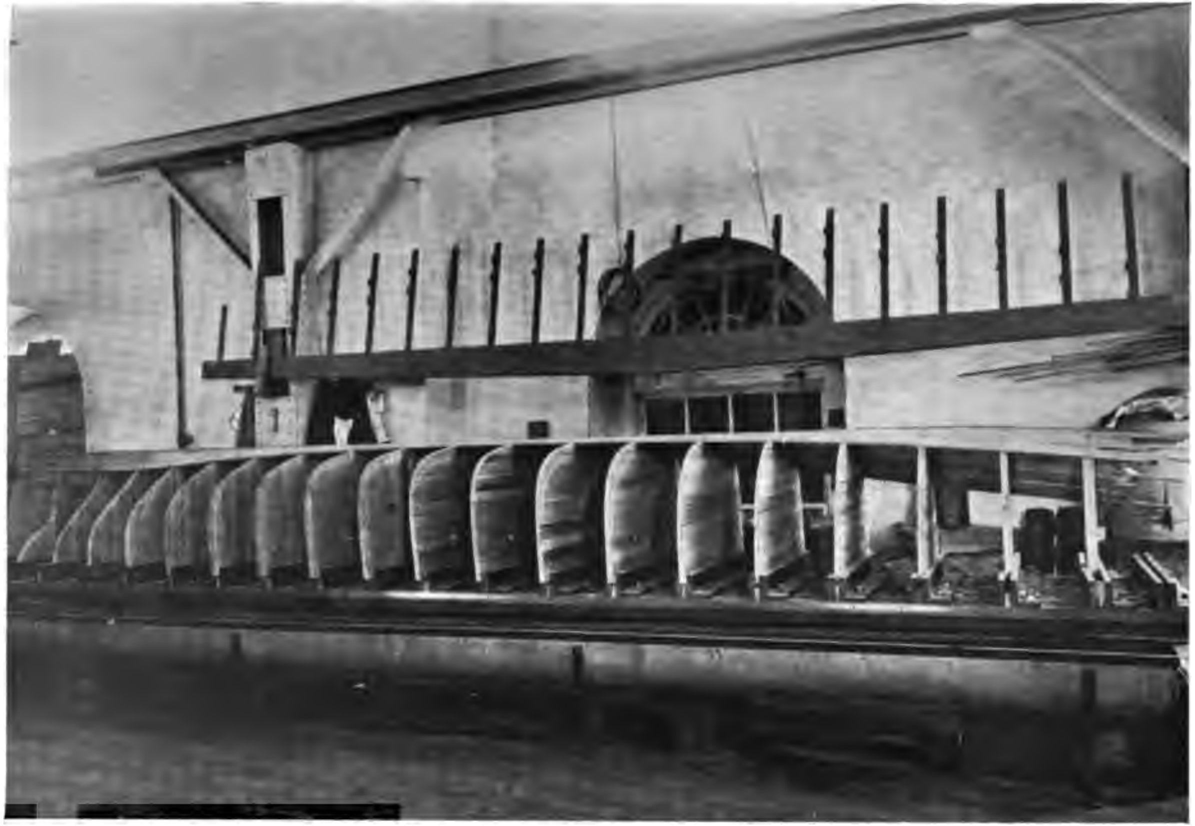

RESISTANCE IN POUNDS
50
40
30
20
10
SPEED IN KNOTS
LEVEL OF BOW AND STERN AT REST FOR NORMAL DISPLACEMENT AND TRIM
STERN LEVEL
BOW LEVEL
SCALE FOR LEVEL. INCHES
CURVES OF RESISTANCE AND CHANGE OF LEVEL
OF MODEL OF
U.S.S. "YORKTOWN"
NORMAL { DISPLACEMENT OF MODEL 2405 LBS.-FRESH WATER
" VESSEL 1680 TONS-SALT "
RATIO OF MODEL TO VESSEL - 1:11-5
LENGTH OF MODEL 20 FT.
CURVE NO. 1 NORMAL DISPLACEMENT AND TRIM
" " 2 " " TRIM 4' BY HEAD
" " 3 " " " " STERN
" " 4 10% HEAVY " NORMAL TRIM
" " 5 " LIGHT " "

FIG. 60.



Naval Construction.—To follow Page 162.

FIG. 61.

Preparation of Models.—Models are as far as practicable made of the standard mean immersed length of 20 feet. The length over all is usually somewhat greater. The model-making apparatus is designed with the idea of working from a body plan. Having a correct body plan upon a certain scale, sections of a 20-foot model corresponding to the sections in the body plan are first determined, using an eidograph, and with the usual scales for drawings and sizes of vessels, it nearly always involves enlargement. The eidograph works upon a table covered with a sheet of glass.

Having properly adjusted the length of arms by means of the scales provided, the pointer on the short arm is run around the sections of the body plan, the pencil on the long arm describing the sections desired upon pieces of paper. These paper sections are used as patterns for use in cutting out the wooden sections for the former model. These are clamped in their proper relative positions upon an iron table and a skin of round strips of wood nailed securely to them. Fig. 61 shows this skin partly in place. This completes the "former model," as it is called, except that plaster is later applied as described below. Its ends are not made to accurately represent the vessel, as it has been found more desirable to rough finish only from the former the ends of the final model and finally finish them by hand.

While the former model is building, a wooden block is built up of white pine planks about 2 inches thick, sawed hollow and glued together hot under heavy hydraulic pressure. This block is so proportioned that when the finished model is cut from it, the wood will be left amply thick, generally not less than about 2 inches. Additional thickness is not especially avoided, as the models require ballast in every case. The former model and its corresponding block are now secured in the model-cutting machine, the former model being below. As may be seen from Fig. 62, the roller below rolls over the former model, and the saw above, driven at high speed, is constrained by the balanced link work to move exactly above and at a uniform distance from it. The sizes are so arranged that the saw does not cut within one-eighth of an inch of the intended finished surface of the model. There are two traversing

cutter heads, one on each side. Each is traversed (by an electric motor) three-quarters of an inch or so at a time and then a saw cut made. Then the superfluous wood is knocked off, the interstices between the battens of the former model plastered with plaster of Paris to give a smooth surface, and a rotary cutter substituted for the saw, with a corresponding roller. This cutter rough-finishes the model to very near its exact size. The model is then removed from the machine and finished by hand, the ends, which are left quite rough, being also shaped by hand from paper patterns or light wooden templates obtained from the lines. Sanded disks, driven at high speed by an electric motor, are used to finish. The models are carefully painted, inside and out, and a standard varnish finally applied to the outside to get a uniform surface.

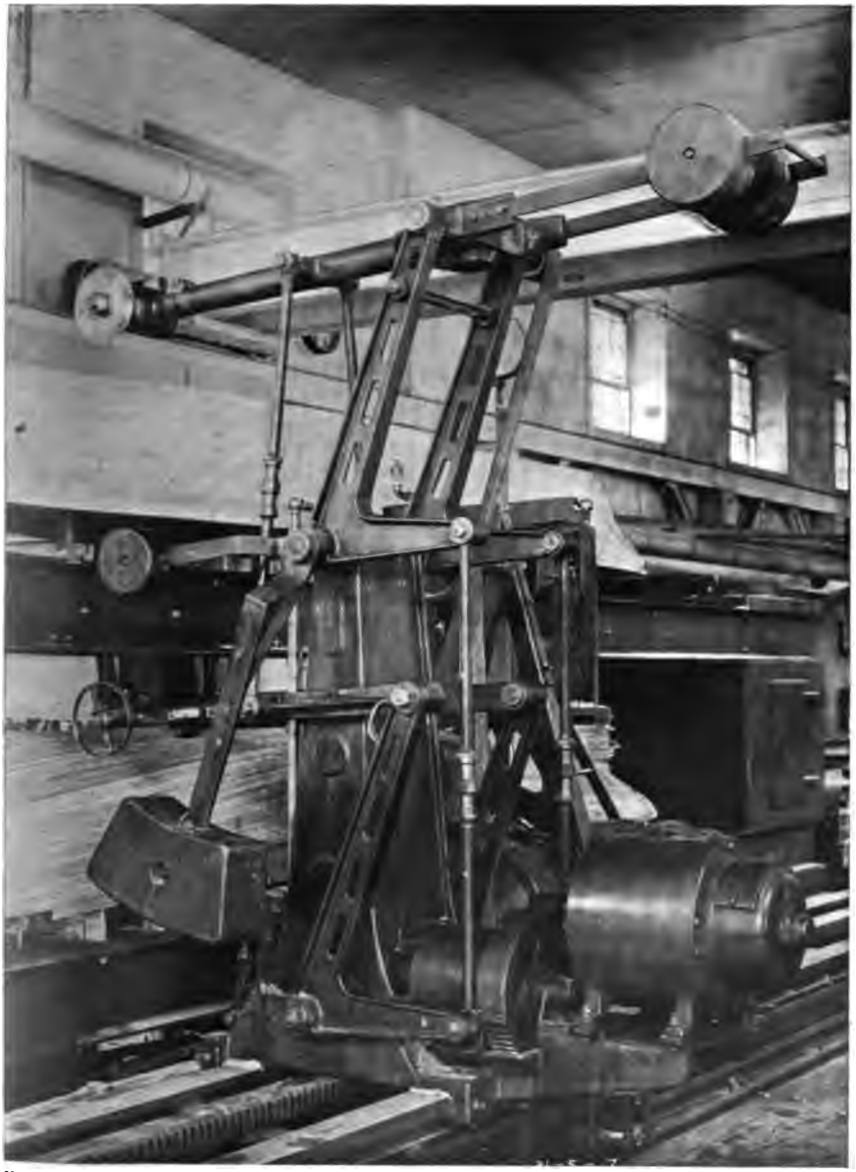
Before being taken to the basin, the models are carefully measured.

From the results of measurement, a body plan is drawn and compared with the original lines to insure that the model accurately represents the ship. All calculations at the model basin are made from actual lines of the models.

The tops of the completed models are parallel to their designed water-lines, and with the level straight-edges fitted in the south end of the basin, it is easy to determine the exact trim of the model when afloat.

All trials are run by weight and draught is used only as a rough check. Before beginning a trial a model is suspended to one of the cranes on the carriage, and weighed. It is then ballasted until its weight is fresh water corresponds to the desired displacement of the ship which it represents. After a trial the model is weighed again for checking after the ballast has been removed. Models are handled by electric cranes, one on the forward side, the other on the after side of the carriage. The models are stowed on the galleries on each side of the basin.

The *dynamometer,* whose object is to record the resistance of the model being towed through the water of the basin, is attached to the carriage which runs to and fro on rails above the water. The model has vertical plates attached to it in the center line at each



Naval Construction.—To follow Page 164.

Fig. 62.

end which play with very little freedom between the pointers rigidly attached to the carriage, so that with practically no friction the model is constrained to move in the same direction as the carriage and without deviation, and at the same time is free to rise and fall, or change trim. The towing rod takes the resistance of the model, and the fore and aft motion of the model, relative to the carriage, is very little.

Plotting.—Supposing the difficulties to have been overcome, we can plot the results of towing experiments upon a model in the shape of a curve, such as *AAA*, in the figure below, showing the resistance in pounds of the model plotted upon speeds as abscissæ. This curve represents the total resistance, made up, as we know, of skin resistance, eddy resistance, and wave resistance.

We also know that the latter two alone (eddy resistance and wave resistance), constituting the residuary resistance, follow the Law of Comparison.

The first step, then, is to deduct from the total resistance the skin friction, which is calculated from the wetted surface and the results of experiments on planes of various character. Setting down the skin friction from the curve *AAA* in the figure, we obtain the curve *BBB*, representing the residuary resistance of the model. Now we know from the Law of Comparison that this curve also represents the residuary resistance of the ship, provided the scales of speed and resistance are suitably changed.

In the case shown by figure, the model was 1/16 the size of the ship; hence, corresponding speeds of the ship and model are in the ratio $\sqrt{16} : 1$ or $4 : 1$, and residuary resistances at corresponding speeds are in the ratio $16^3 : 1$, or $4096 : 1$.

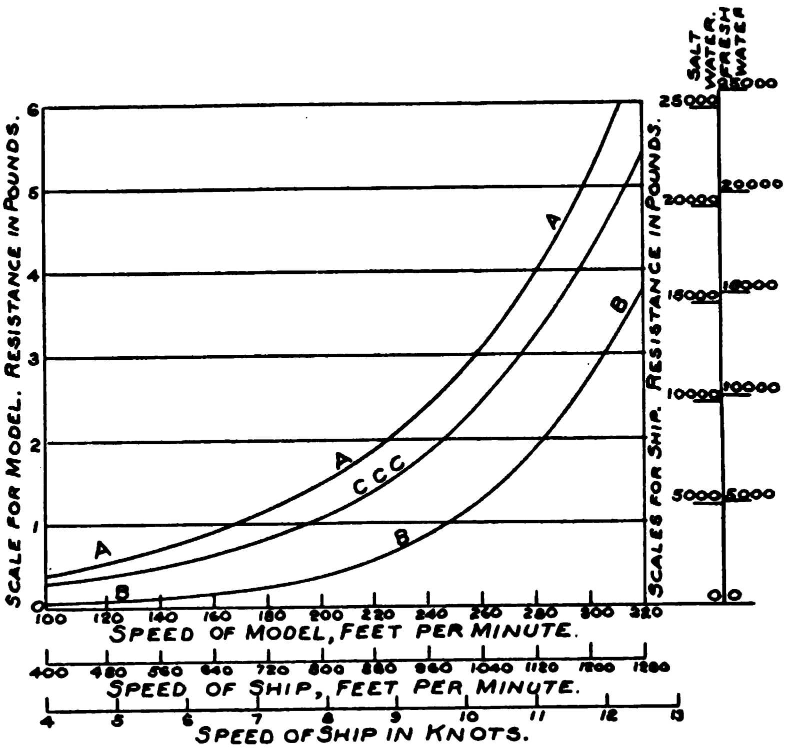
Drawing in the scales for the ship as shown, the curve *BBB* represents the residuary resistance of the ship in either fresh or salt water, according to the scale used.

Salt water resistance $= 1.026 \times$ fresh water resistance.

It is now necessary to calculate the skin resistance of the ship, and set it up above *BBB*, to obtain the curve *CCC*, which represents the total resistance of the ship.

From the above it is evident that the relative resistances of different forms of models may be obtained and plotted in such form as to be readily comparable.

To obtain an estimate of the horsepower required to drive a



given form of ship at certain speeds these resistances and speeds may be readily converted into horsepower by the formula:

$$\text{H. P.} = \text{ft. lbs. per minute} \div 33000.$$

The figures so obtained permit plotting a curve of effective horsepower or E. H. P. required.

The tabulation and careful consideration of results of many experiments and trial trips permit the determination of a factor

giving the ratio between indicated horsepower and effective horsepower, and assuming, after due consideration of the conditions obtaining, a value for this factor, a curve of probable indicated horsepower or I. H. P. may be obtained.

I. H. P. is an expression too well known to require defining.

In the case of turbines, the measure of power obtainable from the completed installation is taken from the shaft and therefore becomes brake horsepower, or B. H. P., and the factor giving the ratio between B. H. P. and E. H. P. will differ considerably from that giving the ratio between I. H. P. and E. H. P.

The foregoing deals only with a small portion of the functions of the experimental tank, which is of value for a wide range of experiments in connection with ship resistance and ship propulsion.

CHAPTER XI.

CLASSIFICATION, BUILDING, LAUNCHING, ETC.

In the U. S. Service, ships are rated as 1st rate, 2d rate, 3d rate, etc. The regulations on the subject of rating are quoted below:

Vessels of the navy shall be classed as follows (Navy Regulations, Article 1035):

(a) First rates, men-of-war of 8000 tons and above.

(b) Second rates, men-of-war only of 4000 tons and under 8000 tons, and converted and auxiliary vessels of 6000 tons and above, except colliers, refrigerating ships, distilling ships, tank steamers, repair ships, hospital ships, and other vessels constructed or equipped for special purposes.

(c) Third rates, men-of-war from 1000 to 4000 tons, converted and auxiliary vessels from 1000 to 6000 tons, refrigerating ships, supply ships, distilling ships, tank steamers, repair ships, hospital ships, and other vessels constructed or equipped for special purposes of 4000 tons and above.

(d) Fourth rates, all other rated vessels.

(e) Torpedo-boat destroyers, torpedo-boats, tugs, sailing ships, and receiving ships shall not be rated.

The general broad classifications of naval ships accepted throughout the world are:

(1) Armored ships, including:

a. Battleships (11,000 to 40,000 tons).

Those expected to do duty in the first line of battle, and carrying, on maximum displacement, the heaviest offensive weapons in combination with the maximum of defensive armor and reasonable speed, 16 to 25 knots.

b. Armored cruisers or battle cruisers (9000 to 25,000 tons).

Expected to do some advance duty, but capable of taking position in the first line, carrying on displacement about equal to battleship, heavy ordnance in combination with medium defensive quality and great speed, 22 to 31 knots.

Recent development of armored cruisers, or battle cruisers so-called, has left it a matter of conjecture, in many cases, as to whether certain ships called battle cruisers should not more properly be called battleships —*Vide:—Invincible, Indomitable.* etc.

c. Monitors (3000 to 6000 tons).

Used for harbor and coast defense (a type now obsolescent).

(2) Unarmored cruising ships (3000 to 10,000 tons).

Including protected cruiser type of medium displacement, with medium offensive qualities, small defensive qualities, and great speed.

Scout class, excelling in speed, but small in other qualities, and of small displacement.

In foreign services very large ships of this class have been built, but in the U. S. Service their displacement has always been kept comparatively small.

(3) Gunboats (800 to 1200 tons).

For patrol and police duty. Small.

(4) Torpedo-boat destroyers (200 to 1500 tons).

Torpedo-boats (80 to 175 tons), (a type now not much used).

(5) Submarines (40 to 1000 tons).

(6) Colliers, hospital ships, and auxiliaries.

Various displacements, according to service.

The Plans of a Ship and Their Reproduction in the Mold-Loft.

The explanation of the sheer draft and the relations which the sheer, half-breadth, and body plans bear to one another, has been given in Chapter II.

After the naval architect has laid down the lines of the ship, it becomes the business of the shipbuilder to accurately execute them. All the shipbuilder needs to find in the plans prepared by the naval architect is the shapes of all the various pieces of the ship; he wants to so shape each piece that it shall exactly find its place, fill its room, and fit its neighbor. The room for each piece, the space or void to be left unoccupied, the junction, face, and fitting around each piece—all *that* is to be exactly defined and measured beforehand on the floor.

The Plans.

The drawings required by the builder consist of:

1st. The sheer draft (see Plate I).

2d. The elevations, plans, sections, etc., showing the details of construction, character, and extent of the principal fittings (see Plates III, IV, and V giving sample plans).

The sheer draft, which serves principally for the reproduction of the lines in natural size, on the mold-loft floor, consists of the following three plans:

1st. The sheer plan.

2d. The half-breadth plan.

3d. The body plan, all as shown by Plate I.

A diagonal plan is sometimes added, as it provides the best and most reliable means of *fairing* the body plan.

The other drawings comprise:

(a) Midship section, and such other transverse sections of the vessel as may be necessary to show the arrangement and size of materials used in her construction (see Plate III).

(b) The profile or longitudinal vertical section of the vessel, showing arrangement of decks, bulkheads, etc. (see Plate IV).

(c) The deck and hold plans (see Plate V).

The drawings, together with a specification describing in detail what the intended ship is to be, having been prepared, the work of preparing a half model of the ship and the laying down in the mold-loft can be commenced simultaneously.

The Model.

The plans being prepared and the scantlings determined, the shipbuilder, while laying off and fairing the body, usually prepares a model (or half model) in wood, of the vessel to be built, and upon that model he draws lines showing position of the frames, and then arranges the edges and butts of the shell plating. Other details, such as the intersection of transverse bulkheads and decks with side, traces of longitudinals, bilge and docking keels, position of outboard valves, struts for propellers, air ports, etc., are frequently added in the case of elaborately-designed ships like men-of-war. The model is usually made upon a scale of ¼ inch to the foot, but for very small vessels a half-inch scale is preferred. From this model, the lengths of the plates and frame angle bars are generally measured, and these materials are ordered as early as possible from the manufacturer.

Sometimes, however, the widths of the plates are measured from a drawing showing an expansion of the bottom and side of the ship.

It is usual to order the shell plates an inch longer than the measurements obtained from the model or expansion plan, except at the more curved parts of the bow and stern, where an excess of from 2 to 4 inches is allowed. In many shipyards, the breadths of the plates are taken from the scrive-board, to be hereafter described. The lengths of the floor plates and reverse angle bars are sometimes obtained from the model or expansion plan, but generally from the body plan or mold-loft floor, or the scrive-board.

Laying Off and Fairing the Body.

Laying off is the name given to the geometrical process, by the aid of which the shipbuilder determines in full size on the mold-loft floor the forms of the various pieces of which a ship's hull is composed, so that when put together in their positions they shall collectively constitute the frame of the ship, having the exact form and dimensions intended by the designer. It may be called the geometry of shipbuilding. Recently in several shipyards and navy yards in the United States, instead of developing full size on the mold-loft floor, the development is made to 1-inch scale on a marble slab (used because it does not expand or contract), and transferred direct to scrive-board in full size.

The advantages of iron and steel over wood as a material for shipbuilding are exemplified not only in the superiority of the ships when built, but also in the comparative simplicity of all operations connected with the building of them. In no department of iron shipbuilding is this relative simplicity more apparent than in that which is carried out on the mold-loft floor. This simplicity, it should be added, is most noticeable in the case of merchant vessels, the skill and labor required in laying off a man-of-war, particularly an armor-clad, beyond that of a merchant vessel, being very considerable. This is due principally to the fact that men-of-war are built on the bracket system, with both longitudinal and transverse framing, as well as to the more complicated system of their subdivision by decks, flats, bulkheads, etc. The unarmored vessel is somewhat simpler, the problem of the longitudinal being the only addition of importance to the simpler case of the merchant vessel built on the transverse system.

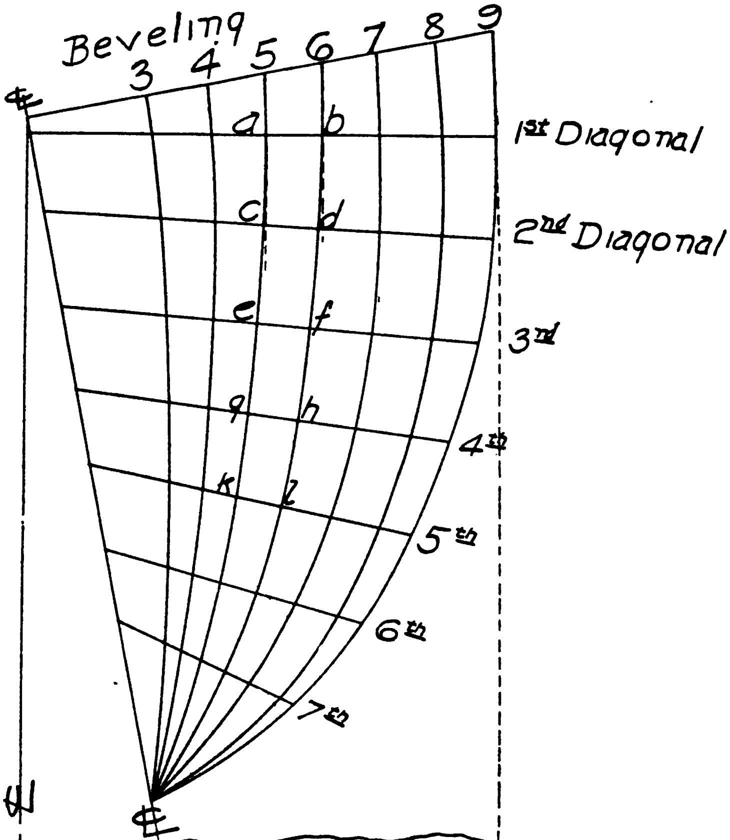
It will be sufficient for our purpose to state that, in its simplest form, "laying off" resolves itself into but little more than simply fairing the lines upon the sheer draft. This drawing is usually prepared upon a ¼-inch scale, and although every care is taken in fairing the lines upon it, yet, when expanded to full size, or even to ½-inch scale, discrepancies and points of unfairness are sure to be discerned. It has already been shown that the projections of each of the set of lines generally used in this process—waterlines, bow and buttock lines, diagonal lines, etc.—appear straight in one or two of the plans of the sheer draft, and curved in the others. The property which a wooden or metallic batten has of bending in a fair curve is brought to our aid in drawing the lines fairly in the plan where they appear curved. The points of intersection of two sets of lines in one plan are transferred to their relative positions in others, and it will be found that points which in one plan were in a straight line are, when transferred to another view, in a curved one. A batten is bent to pass through as many of the points as is consistent with absolute fairness, and the line is drawn. Thus, by a series of interchanges from one plan to another, the various lines are drawn in full size on the mold-loft floor until at length all the plans agree, the lines composing them are fair curves, and having thus evidence of a continuous surface, the body is said to be *fair*.

In some yards, molds for all work are prepared directly from the plans on the mold-loft floor, but in others the body plan is transferred to the scrive-board. This consists of a number of thoroughly seasoned planks secured edge to edge by clamps, the area of the "board" being large enough to receive a copy of the body plan to full size.

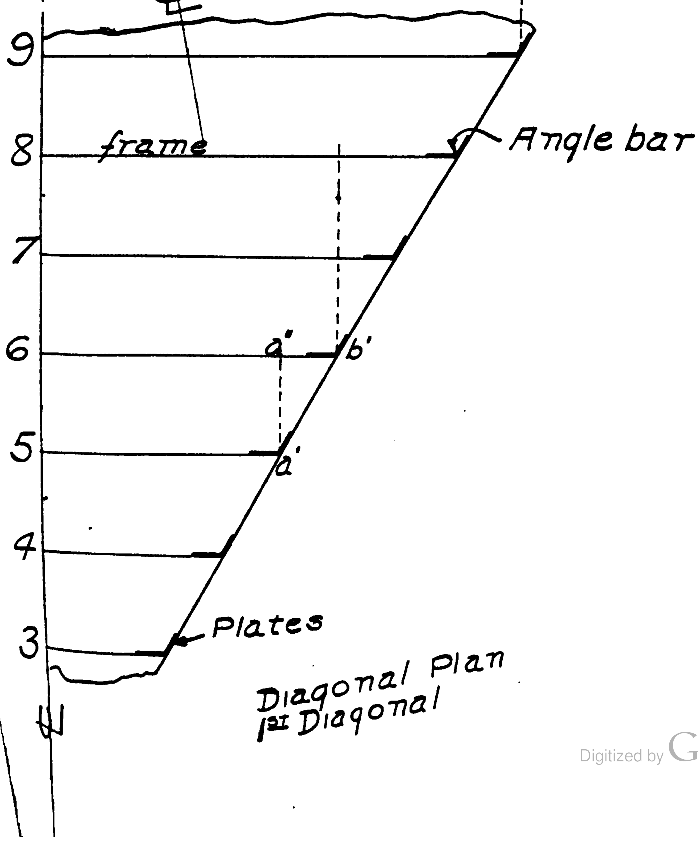
As the scrive-board is kept near the bending slab, the necessary dimensions have to be taken off on battens in the mold-loft and transferred to the board.

The scrive-board should show:

1. The base line, middle line and boundary lines, waterlines, bow and buttock lines, and diagonal lines.
2. The outer edge of the frame and angle bars.
3. The inner edges and upper boundaries of floor plates.
4. The sight and landing edges of shell plates.
5. The lines of the upper side of beams at the outer edges of the frames.



y Plan
. 63



ig. 64

Diagonal Plan
1st Diagonal

6. The middle line keelson, side stringers, etc.

7. The position of ribbands for holding the frames in their proper places (if they do not coincide with the diagonals).

8. When an inner bottom is fitted, the longitudinals are shown at each transverse section, together with the margin plates and such other lines as may be necessary in such cases.

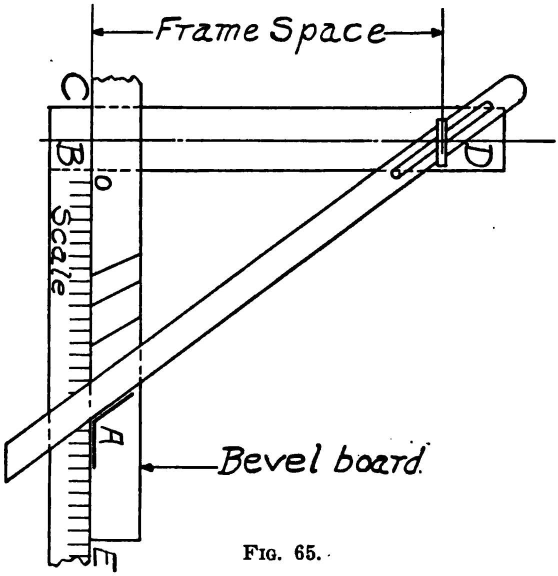


FIG. 65.

All these lines are *razed* or scratched into the surface of the board, and some of them are distinguished by paint marks of various colors.

In order to protect the scrive-board from being burnt by the *set iron* or by the frames when checking their curvature, strips of half-round iron are fastened on the surface of the board, these being placed between the plate edges, and in directions about parallel to the latter.

Bevelings.

Beveling boards have to be prepared for the use of the workmen when setting the frames and reverse frames to the curves shown on the scrive-board.

The bevels are taken either from the body plan in the mold-

loft, or from the scrive-board, and are generally taken and applied at the intersections of the diagonals with the frames.

Since the principal frames of a ship are so set that the planes through them are perpendicular to the line of the keel or center line, it is evident that, on account of the curvature of the hull towards the bow and stern, the moulded edge of frames would not be normal to the outer plating of the hull except near the middle body where the contour of the hull is parallel to the center line. Consequently the outer flange or faying surface of the frame angle bar must be brought to the contour of the hull by opening the angle, in order that the flange may present a flush surface for riveting the hull plates to the frame angle. This is known as beveling.

Figure 63 shows the body plan of the ship (with diagonals and frames only) as drawn on the scrive board. Figure 64 shows the diagonal plan on the first diagonal (*i. e.,* section on first diagonal). Suppose, for instance, the beveling is required for frame No. 5 at the first diagonal, the procedure is as follows: On the body plan, the distance ab is measured *on the diagonal* and equals $a''b'$ on the diagonal plan — $a''a'$ being drawn parallel to center line — or line of keel. This distance, ab ($= a''b'$), is laid off on the bevel scale, $= AB$, while the distance CD equals the fore and aft space between frames (5-6 on diagonal plan), usually 4′, and $AD = a'b'$.

Then $\angle ADB = \angle a''a'b'$. But $\angle DAE = \angle ADB + 90° = \angle a''a'b' + 90°$ = angle of beveling required. Two men operate the bevel lifter, Fig. 65. One measures off the projected distances between frames *on the diagonals,* calling out the distance to the other who sets the tongue of the bevel lifter to the point on the scale and marks the angle on the bevel board. This process is repeated to obtain the angle of beveling at the various diagonals; thus for 2d diagonal the distance cd is laid off, for the 3d ef, etc., until the angles for the entire frame at the various diagonals are obtained. The bevel board is moved along slightly as each angle is scribed and each bevel is numbered. The bevel is always an obtuse angle since the outer flanges of the angle bars for the forward frames are turned aft and the outer flanges of the after angle bars are turned forward in erecting.

The frame and reverse angle bars are bent to their required form on the *bending slab* (see Fig. 66). This is composed of a number of square blocks of cast-iron with holes in them as shown. These

blocks are fitted together, side by side, upon the ground until their united surfaces give a sufficient area for receiving the full length of any frames or other angle bar in the ship when bent.

The first operation in frame bending is the preparation of the *set iron*. This is a bar of soft iron varying from $2'' \times \frac{5}{8}''$ to $1\frac{1}{4}'' \times \frac{3}{8}''$, according to the size of the vessel.

The curves of the frame are deeply scratched upon the scrive-board, and that particular frame to be bent is carefully traced out with chalk. The set iron is then bent accurately to the shape of the

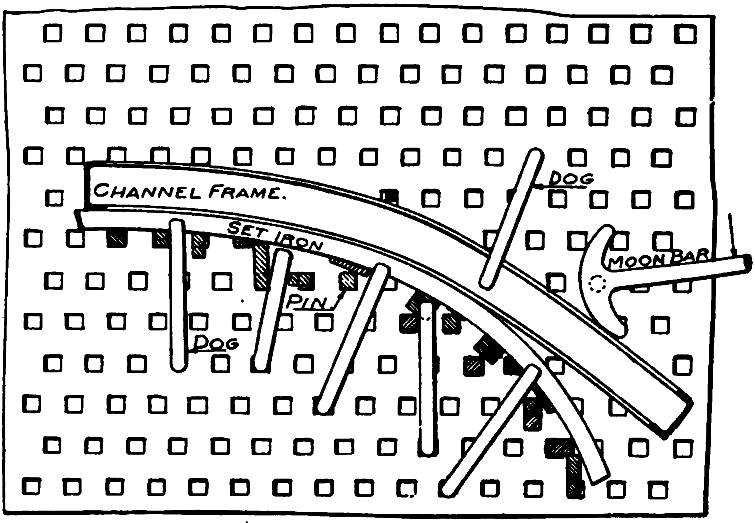


FIG. 66.—BENDING SLABS.

curve of the frame upon the scrive-board, and the positions of the beveling spots, usually the ribbands, are marked upon it. The set iron is then taken to the bending slab, and the curvature is transferred thereto with a thin slip of chalk. In some yards, instead of a set iron, a template of thin wood is made for each frame from the scrive-board and carried to the slab.

The curve drawn upon the bending slab is that of the outside of the frame, and at a parallel distance from it equal to the breadth of the transverse flange, the curvature of the inside of that flange is drawn by means of a gauge. The next step to be taken is one for

which no rule can be laid down, as it is determined by the experience of the workmen.

It is found that in cooling, a bent angle bar not only shrinks, but also loses a portion of its curvature. A point is therefore fixed several inches beyond that given by the set iron for the extremity of the frame, to allow for contraction. At the same time a point is fixed within each extremity of the curve and the set iron is adjusted to a new curve passing through these extreme spots. In this way several inches greater curvature is obtained than is shown by the scrive-board, in order to allow for the subsequent straightening of the angle bar when cooling.

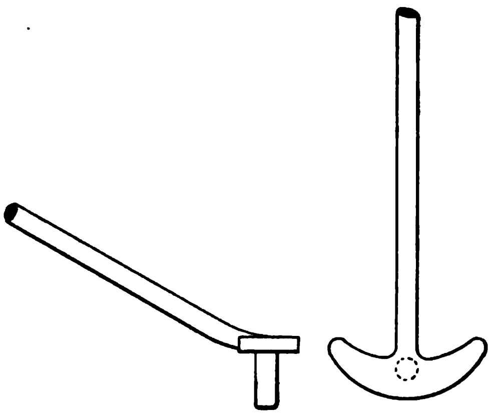


FIG. 67.—MOON BAR.

Pins are then driven in the holes of the bending slab which are nearest to the set iron, the pins being on its concave side. The intervening spaces, if any, between the pins and the set iron may be filled with circular or oval washers placed upon the pins.

All this time the frame angle bar is in a long reverberatory furnace being heated to a bright redness, almost to whiteness. When ready, it is taken from the furnace; and end of the bar is fixed by pins on both sides to the corresponding point on the slab, and then by the aid of a lever, or moon bar, such as is shown in Fig. 67, and by men pulling on a chain attached to the extremity of the bar, the latter is bent to the required curvature and secured in this position by bent pins called *dogs,* as shown in Fig. 66.

Except at the extremities of the vessel, where the beveling is very considerable, frames usually are given such beveling as they require after being bent. The beveling is always *standing,* or obtuse, and for this purpose, the flanges in the forebody look aft, and in the after body, forward. The bevels having been set to the bevelings required at the different ribbands, are applied to the angle bar at the corresponding positions, and the necessary beveling is given to the bar while it is still hot, by blows from a hammer and by the aid of a suitable tool.

When the beveling is very considerable, it is generally given before bending, as the bar, being of thin substance, soon loses its heat, and after being bent becomes too cool to bevel satisfactorily. In large yards nowadays beveling is generally done before bending, by a beveling machine, and the final setting only done by hand. The final operation is to mark upon the angle iron the positions of plate edges, harpins, and other important points, nicking them with a cold chisel.

Frames for warships are generally punched for riveting after bending. Care should be taken to punch the holes *from the faying* surface (that is, the surface against which the plate lies), in order that the holes may be largest on the inside of the vessel, the hole being smallest where the punching tool enters. Rivets are generally made with a conical form under the head, so as to completely fill the rivet holes when hammered up and clinched.

Where the plate lap crosses the frame, only one rivet hole is made, in order not to weaken the frame, and this hole is always in the outer row.

The keel blocks are laid on ground previously strengthened by piling if necessary. The spacing, declivity, and sizes of the blocks are governed by the dimensions and weight of the ship to be built. The declivity is usually somewhat less than the ways subsequently laid for launching.

The height of the foremost block from the ground must be determined with great accuracy, as if there is a difference between the declivity of the blocks and launching ways, the bow comes continually nearer the ground as the ship slides into the water.

The inner and outer flat keel plates are first planned and rivet holes punched or drilled, and after being carefully fitted, are temporarily secured to the blocks in the correct position; next the vertical keel plates and angles are fitted and their holes punched or drilled, and then the stem and sternpost, frames and longitudinals.

To keep the frames to the required form of the ship, *harpins* and *ribbands* are employed. The latter are usually made of pine and are employed at the comparatively straight parts of the ship, while the harpins, made of oak or elm plank, trimmed to molds and bevelings, obtained with great accuracy from the mold-loft plans, are used for the more curved parts of the ship's sides. These are situated near the longitudinals, yet sufficiently clear of them not to be in the way of fitting that portion of the framing.

The ship being framed, rabbanded and faired, the beams, stringers, and longitudinals riveted in place, the plating is proceeded with. In some yards, special practice obtains as to this, and the plating of the shell is begun first, the frames being set in place on top of the plating.

The strakes are lettered on the plans from the keel up, and each plate numbered in its own strake, so each plate is marked for its proper place when received. The inner strakes, *i. e.,* those fitting close against the frame bar, are always fitted first, and then the raised strakes. The edges and butts are lined off and both planed to the lines.

To give the necessary curvature to the plates, they are bent between iron rolls of the necessary length. These rolls are usually three in number. The upper roller rests in bearings, being free to revolve, but is not turned by the machinery which turns the lower two. It can be raised or lowered as circumstances require, depending on the curve desired. When being bent, the plate is lifted by a number of men, under the direction of the "plater" in charge, who hold the plate, generally with a crane, in the desired position for getting the necessary curvature and twist. The plates are bent cold unless very great curvature is required.

The plates are carefully fitted to their places and secured to the frames by means of nuts and screw bolts. It is most important

that the process of "bolting up" should be carefully and thoroughly done, so that the strakes may be set closely against the frames and the butt straps against the plates. When the outer strakes have been fitted and temporarily secured, the work of riveting can be begun. It is desirable that this should not be unduly delayed after the plates are screwed in place, for since the nuts and screw-bolts do not fill the rivet holes, there is always a tendency for the plates to sag.

It has only been attempted in this chapter to give a general idea of the order of the work. Details differ in different shipbuilding works, according to the practice of the yard, and change with the progress of inventions, tools, qualities of metals, etc.

Launching.

Ships, after building, require to be put in the water. This process is called *launching*.

Ships, in building, are supported on blocks forming what is called the *building slip*. These blocks, for U. S. warships, are generally 4 feet apart and their upper surface forms an incline, the declivity of which varies with the size and type of ship, varying with weight and character of ship from about $\frac{1}{2}$ inch per foot to $\frac{5}{8}$ inch per foot. While building, the keel rests on these blocks, and the ship is supported otherwise by shores and cribbing suitably spaced at the sides, under the bilge, etc. The building slip is generally perpendicular, or nearly so, to the shore line, in coastwise building, though on the Lakes, ships are often built broadside to the shore line.

When preparing for the launch, two timbers or combinations of timbers are laid down, one on each side of the ship and parallel to the ship's length, or nearly so, the distance apart being usually about one-third the beam of the ship. These timbers, called *ground ways,* are inclined to the horizontal in the direction of the length of the ship, at a slightly greater angle than the top of keel blocks on which the ship rests, the outer end being carried some distance out into the water; they are generally slightly inclined inwards and fitted on the outboard side with a guide timber or ribband. These ground ways are securely shored and fastened to

Naval Construction.—To follow Page 180.

FIG. 68.—VESSEL ON WAYS READY TO LAUNCH.

the ground to prevent spreading or moving. The top surface of these ways is covered with tallow or other suitable grease whose nature is dependent on the weight of the ship and the temperature of the weather at time of launch.

On top of these ground ways are placed sliding ways which are packed up to the ship with timbers, forming a cradle in which the ship rests. These cradles are cross-connected by lashings under the keel, and the combination of sliding ways, ship, and cradle move together. Prior to launching, these sliding ways in which the ship rests are securely bolted at the shore end or sole piece to the ground ways.

When the vessel is ready to launch, wedges are placed between the sliding ways and the packing, and driven home, raising the weight of the ship off the keel blocks and bringing it on to the ways. The shores and keel blocks are then removed, allowing the ship to rest on the ways only. When ready to launch, the sole pieces are sawn off and the ship slides into the water on the grease on the ground ways. See Fig. 68, showing vessel on ways ready to launch. A model on view in the model-room shows the method of blocking and cradles employed for launching.

It is often necessary, in confined waters, to adopt means for stopping the motion of the ship to prevent its running aground or damaging other shipping. Various means are employed to this end, such as fitting a mask over the stern to offer resistance to motion through the water, breaking stops on bights of chain, pulling wedges through resisting orifices, etc.

For detailed data of launchings, see paper by the author in Transactions of the Society of Naval Architects and Marine Engineers, 1904, and other papers in that volume and before.

Docks and Docking.

When a steel vessel becomes foul after having been for some time in the water, she requires to be docked and repainted. To do this, it is necessary that she be put into drydock, or otherwise placed where her underwater hull will be exposed. In the old days of wooden ships it was not unusual to accomplish this by heaving down or careening. Where on a shelving beach, the vessel was hove down by tackles to her mastheads, and when the tide went out, a considerable portion of her underwater body was exposed.

UNITED STATES NAVAL DOCKS.

Yard or station.	Dock No.	Kind.	Material of which dock is constructed.	Class of maximum ship capable of being docked.	General dimensions. Body of dock. Length coping head to side of caisson.		Length on floor head to outer sill.		Width at coping.		Width top of keel blocks.		Depth mean high water to keel blocks.		Entrance. Width at coping.		Governing width 6 feet above sill.		Depth mean high water to sill.	
					ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.
Portsmouth	2	Dry dock	Granite and concrete	Utah	740	10½	718	10½	130	0⅜	[1] 96 [2] 92	8⅜ 8⅜	30 28	2⅝ 8⅝	101	9	91	2	30	2⅝
Boston	1	....do....	Granite	Raleigh	373	11⅝	357	1	86	1½	[1] 56 [2] 48	2⅜ 2⅜	22 19	0⅝ 6¼	60	3	46	10¾	25	1⅛
Do	2	....do....	Granite and concrete	Utah	738	1	729	0	114	0	[1] 86 [2] 82	0 0	30	0	101	8⅝	91	4½	30	0
New York	1	....do....	Granite	Monterey	349	1½	326	3¾	98	1 3/16	[1] 56 [2] 48	1 3/16 1 3/16	22 20	1⅞ 11⅜	67	1 3/16	47	6	25	4⅜
Do	2	....do....	Concrete	Missouri	462	0¾	451	8¼	112	10¾	74	6	25	3	90	6¼	75	6	26	6¼
Do	3	....do....	Wood	Mississippi	656	4⅛	624	0 3/16	150	10 13/16	72	2	27	5¼	105	4 7/16	77	0 13/16	29	8⅜
Do	4	....do....	Granite and concrete	Largest contemplated	694	6	694	9	139	6	112	0	32	11⅛	120	3½	112	0	35	5¼
Philadelphia	1	....do....	Wood	Minneapolis	491	7¼	459	10½	131	8⅛	58	7⅞	22	11⅛	86	0	57	9⅞	25	1¼
Do	2	....do....	Granite and concrete	North Dakota	744	6¾	731	10½	140	2¾	97	0¾	27	10⅜	102	7¼	91	10	29	10¾
Norfolk	1	....do....	Granite	Cheyenne	324	0⅛	303	0	86	8½	....		....		60	0½	....		25	1⅞
Do	2	....do....	Wood	Minneapolis	490	4½	459	8	130	4	57	0	24	10⅞	85	0	58	8	25	6¾
Do	3	....do....	Granite and concrete	Largest contemplated	722	11	732	0	136	0	98	1¾	31	0¼	112	4 3/16	101	0	31	0¾
Charleston	1	....do....	....do....	Utah	566	0	548	0	184	0	96	2	31	1⅛	113	0⅞	101	11⅞	31	1⅛
Mare Island	1	....do....	Granite	Charleston	507	11¾	459	1¾	122	0	45	0	27 25	0⅝ 9⅝	80	6⅞	61	0	26	8
Do	2	....do....	Granite and concrete	North Dakota	740	4⅝	729	10⅝	120	0	88	0	28	9⅝	101	11¼	92	8½	30	8⅝
Puget Sound	1	....do....	Wood body, masonry entrance	Mississippi	636	11⅝	618	7¾	130	1½	76	3¼	28	0½	92	8⅛	74	0	29	10⅛
Do	2	....do....	Granite and concrete	Largest contemplated	827	6	801	8	145	0	113	0	35	6	123	9⅛	114	4	38	0
Pearl Harbor	1	....do....	....do....	....do....	999	6	1008	0	138	0	114	0	32	2⅜	123	0	114	4	34	8⅜
Polloc, P. I.[3]	1	....do....	Stone	Tug	110	0	....		....		....		....		30	0	....		7	8⅜
Pensacola	1	Floating dry dock	Steel	Chicago	450	0½	....		85	8⅝	78	0	20	0	....		....		....	
New Orleans	1	....do....	....do....	Vermont	525	0	....		100	0	....		28	0	....		....		....	
Olongapo	1	....do....	....do....	Connecticut	500	0¾	....		99	10½	....		30	0	....		....		....	
Port Royal[3]	1	Dry dock	Wood	Olympia	485	0	....		126	0	50	0	26	0	97	0	70	0	26	0

[1] Maximum. [2] Minimum. [3] Out of commission or abandoned.

UNITED STATES NAVAL DOCKS.

Yard or station.	Dock No.	History of construction.		Channel from dockyard to sea.				
		Date of commencement.	Date completed.	Mean rise and fall of tide.	Controlling depth yard to sea mean low water.	Controlling width yard to sea.	Maximum draft ship for channel at mean low water.[1]	Maximum draft ship for channel at mean high water.[1]
				feet.	*feet.*	*feet.*		
Portsmouth	2	1899	1906	7.8	40.0	500	Largest contemplated	Largest contemplated.
Boston	1	1827	1833	9.6	35.0	540	....do	Do.
Do	2	1899	1905	9.6	35.0	540	....do	Do.
New York	1	1841	1851	4.2	31.0	450	....do	Do.
Do	2	1887	1901	4.2	31.0	450	....do	Do.
Do	3	1893	1897	4.2	31.0	450	....do	Do.
Do	4	1905	1913	4.2	31.0	450	....do	Do.
Philadelphia	1	1889	1891	5.9	25.5	600	West Virginia	Do.
Do	2	1899	1908	5.9	25.5	600	....do	Do.
Norfolk	1	1827	1834	2.8	27.0	450	Idaho	Do.
Do	2	1887	1889	2.8	27.0	450	....do	Do.
Do	3	1903	1911	2.8	27.0	450	....do	Do.
Charleston	1	1902	1908	5.2	22.0	300	Baltimore	Mississippi.
Mare Island	1	1872	1891	4.8	20.0	300	Newark	Georgia.
Do	2	1899	1910	4.8	20.0	300	....do	Do.
Puget Sound	1	1892	1896	7.8	42.0	984	Largest contemplated.	Largest contemplated.
Do	2	1908	1913	7.8	42.0	984	....do	Do.
Pearl Harbor	1	1909	(2)	1.2	35.0	600	....do	Do.
Polloc, P. I.	1	....	....	4.8	100.0	18,000	....do	Do.
Pensacola	1	....	1897	1.1	30.0	300	....do	Do.
New Orleans	1	1899	1902	....	28.0	200	Delaware	Delaware.
Olongapo	1	1903	1905	4.0	70.0	2,500	Largest contemplated.	Largest contemplated.
Port Royal	1	....	1895	7.0	21.0	200	....	

[1] 12-inch clearance under keel. [2] Under construction.

The modern method takes one of three forms, *i. e.*, by exposing the bottom by means of:

(1) Graving docks.

(2) Floating docks.

(3) Marine railway.

A graving dock (see Fig. 69) is, in essentials, a basin excavated from the earth and lined with stone, concrete, wood, or other suitable water-tight material, and having a gate or mouth connected with the harbor and fitted with suitable water-tight gates or caisson. The whole has to be provided with a pumping apparatus of large capacity.

The operation of docking, in brief, is then as follows:

The dock is flooded by opening the valves provided for the purpose in the gate or caisson. When the level of water inside the dock is the same as that outside, the caisson, which is held in place by being full of water, is pumped out until it floats up out of its seat (or if gates are fitted, the gates are opened) and removed. The vessel is then brought to the mouth of the dock and the lines for handling her passed on board. There are generally 5 on each side—2 forward, 1 amidships, and 2 on quarter—and a head line for hauling the ship in. By keeping these lines tending in proper directions, the position of even the heaviest ship may be readily controlled.

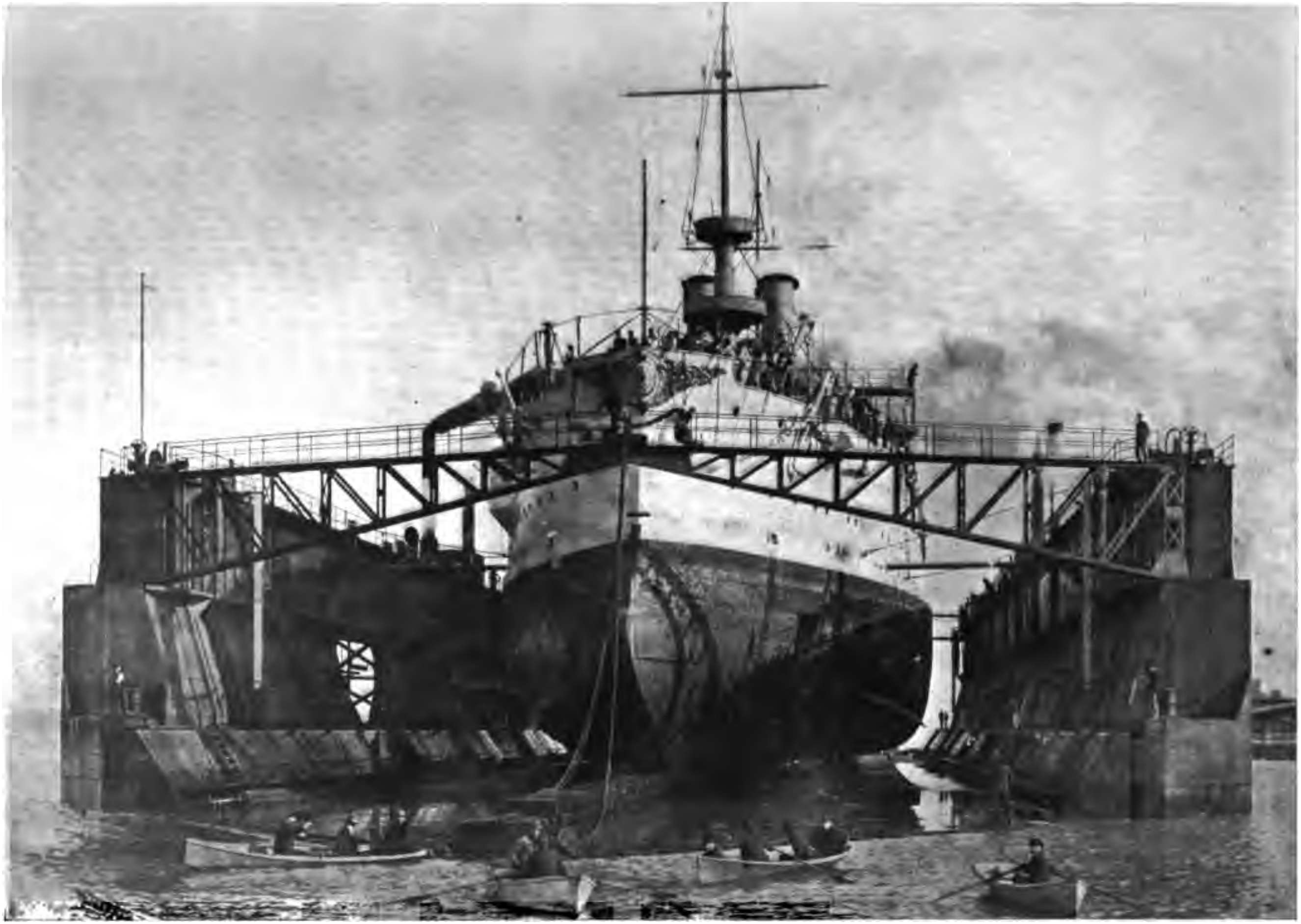
It is essential that the vessel be properly centered in the dock and located exactly in a fore and aft position, and suitable sighting battens and measuring arrangements are provided on the dock coping for this purpose.

In the U. S. Service, the regulations provide that docking shall be done by the Naval Constructor of a yard, and he is responsible for the vessel from the time her bow reaches the sill, going in, until it crosses it, going out.

Vessels generally go into dock bow first. While in dock it is essential that no radical change in the distribution and amount of weight on board be made, such as putting on board or removing considerable amounts of coal or water, or shifting ammunition or coal from one space to another, and no change should be made

Naval Construction.—To follow Page 184.

FIG. 69.—BATTLESHIP IN DRYDOCK.



Naval Construction.—To follow Fig. 69. Fig. 70.—Battleship on a Floating Dock.

without the knowledge of the officer responsible for the vessel while in dock.

When the ship is properly located, the caisson is floated back into place, sunk into its seat, and the pumps started; and as the water inside the dock goes down, the vessel settles onto blocks fitted in the bottom of the dock to receive the center-line keel and docking keel's, and is supported by these, together with certain sliding blocks under the bilges, and shores fitted at sides and under bilges.

The table on Pages 182 and 183 shows the number, kind, and size of U. S. Government drydocks, with their location:

Floating docks are radically different. They are huge box-structures of steel or wood, with high sides and open ends, as shown in Fig. 70. They are fitted with flooding and pumping arrangements of large capacity. When it is desired to dock a vessel, the floating dock is sunk so that nothing but the sides project above the water. The ship is then towed in between the walls, and the dock is pumped out and rises, so that it lifts the ship, which rests on keel blocks arranged in the same manner as for graving docks.

Great skill is required in handling a dock of this character, to prevent straining the dock and the ship to be docked. Such a dock is cheaper in first cost than a graving dock, but obviously requires more care, being as it is, a floating structure. It therefore requires to be docked itself, and is usually made in three sections so that the individual sections may be docked separately by the other two.

Marine railways.—This method of exposing the underwater portion of a vessel is applicable only to the smallest size of warships. It consists essentially of an inclined railway projecting out into the water on which travels a cradle with a suitable endless-chain hoisting arrangement, such that the vessel can be hauled up out of the water on this way, in about a reverse process to that of launching.

NOTE.—For additional data as to docks, see Notes on Docks and Dock Construction, by C. Colson.

For balance of chapter, see U. S. Naval Regulations, Transactions Society N. A. & M. E.; Watson's Manual of Laying off

CHAPTER XII.

MATERIALS, TESTS AND FASTENINGS.

In general the structural material used in U. S. naval vessels is mild steel. It is manufactured under specifications issued by the Navy Department and tested by inspectors detailed by the Navy Department, who in most instances follow the course of manufacture as well as inspect and test the finished materials. The specifications for structural materials are changed from time to time to keep pace with the development of the art of shipbuilding and of the manufacture of steel. The general instructions as to inspection and testing and the manner of making such inspection and tests are contained in a publication issued by the Navy Department called " General Specifications for Inspection of Material." In addition to this there is issued for each character of material, a leaflet or pamphlet specification defining the physical and chemical requirements for that particular material.

The following extracts from the General Specifications referred to above, Edition October, 1913, give in outline the general manner of conducting such inspections:

General Quality.

Uniform quality to be supplied.—All material shall be of uniform quality throughout the mass of each object, and free from all injurious defects. The discarding of inferior portions of ingots, treatment, and manufacture generally, shall be so conducted as to insure uniformity in the quality of the metal of each heat, lot, or object submitted for inspection.

Testing.—All material for which tests are prescribed shall, when practicable for the bureau to so arrange, be tested and inspected at the place of manufacture, and shall be passed by the inspector, sub-

ject to the restrictions mentioned herein, as having complied with the particular specifications under which the material was ordered, before acceptance at the navy yard or shipyard.

Chemical Properties.

Chemical analysis.—Drillings, turnings, or cuttings for chemical analysis must be fine, clean, and dry, and must be so taken as to fairly represent the heat, lot, ingot, or other object for which the analysis is taken. The inspector representing the bureau concerned may have these drillings, turnings, or cuttings taken from test coupons, or from any part or parts of the material represented by the analysis, provided in the latter case that by so doing the material will not be rendered unfit for use.

Physical Tests and Test Pieces.

Care and calibration of testing machines.—Tensile tests should be made by the use of a testing machine of standard make, kept in good condition. All knife edges should be kept sharp and free from oil and dirt. Such a machine should be sensitive to a variation of load of one two-hundred-and-fiftieth of the load carried. Testing machines should be calibrated once in twelve months, and at such other times as may be considered necessary by the inspector representing the Navy Department.

Pulling speed.—Each tensile test piece shall be subjected to a direct tenstile stress until it breaks, running at a pulling speed of not less than 1 inch and not more than 6 inches per minute for 8-inch test pieces, and not less than ½ inch and not more than 3 inches per minute for 2-inch test pieces. Increasing or decreasing the speed on the testing machine while the test piece is under stress will not be permitted.

Interpretation of terms.—The elastic limit may be determined by observing the yield point as found by the drop of the beam or the halt of the gage of the testing machine. The elongation is that determined after fracture. In the case of test pieces of rectangular section the reduction of area is to be measured by the product of the

average width and thickness of the reduced area and not the minimum width and thickness.

Types of test pieces.—Tensile test pieces shall have the dimensions shown in Fig. 71, which are the standard test pieces. If the manu-

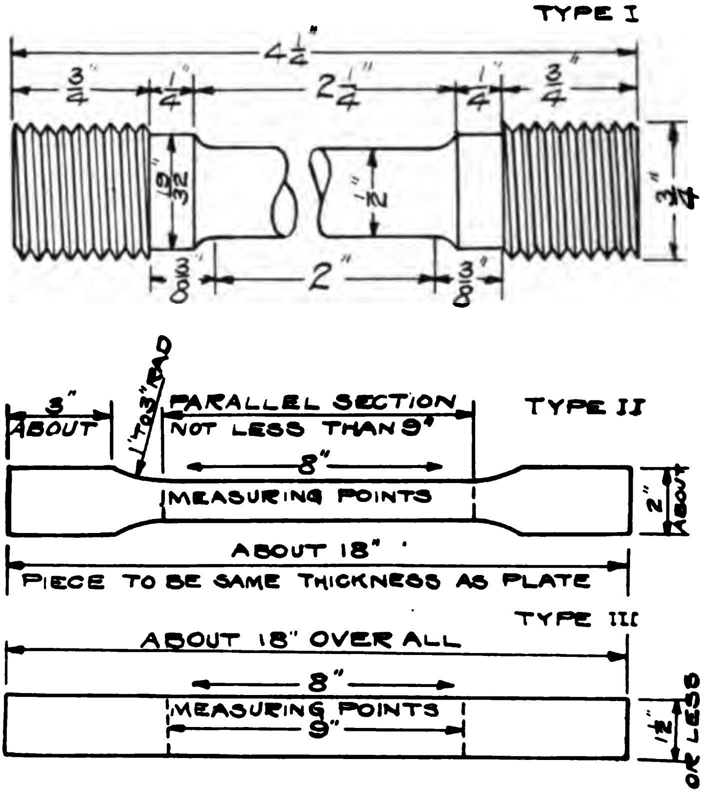


FIG. 71.—TYPES OF STANDARD TEST PIECES.

facturer desires, he may be permitted to use the turned specimen unthreaded if a proper method of gripping the test piece is used. When specimens of Type II cannot be obtained from shapes whose sizes do not permit of making other than straight-sided pieces, the use of Type III may be authorized by the inspector.

Full size test pieces.—All tests, when practicable, shall be made

with pieces of the full size, thickness, or diameter of the material represented by such test specimens.

Length of test pieces between measuring points.—Test pieces from blooms, large rolled bars exceeding 2 inches in diameter, forgings, and castings are to have a length between measuring points of 2 inches. Other test pieces are to have a length between measuring points of 8 inches, except as otherwise directed in these, or in the Navy Department leaflet specifications.

Uniform section of test pieces.—Tensile test pieces shall be uniform in cross-section between measuring points.

Variation of area.—A variation of 5 per cent above or below the standard area will be allowed in test pieces.

Location of test pieces.—All test pieces of forgings, and of rolled bars which are too large to be pulled in their full size, shall, unless otherwise specified, be taken at a distance from the longitudinal axis of the object equal to one-quarter of the greatest transverse dimension of the body of the object, not including palms and flanges.

Test pieces for groups or lots.—Test pieces which represent heats or lots shall be taken, as nearly as the case will permit, so as to represent the metal which was nearest the top and bottom of the ingot; when practicable test pieces shall be taken from different ingots of a melt. Generally speaking, test pieces representing groups of lots should represent, as nearly as the case will permit, the worst material in that lot.

Flaws in test pieces.—Test pieces which show defective machining or which show flaws after breaking may be withdrawn at the request of the manufacturer and others taken under the direction of the inspector; also, new test pieces may be selected and tested to replace any which fail by breaking within a distance from the end measuring points equal to 25 per cent of the length over which the elongation is measured.

Bending test pieces—edges rounded.—Bending test pieces for blooms, large rolled bars (exceeding 2 inches in diameter), forgings and castings, shall be 1 inch wide by ½ inch thick. Specimens for cold bends for plates and shapes shall be rectangular in cross-section

of the thickness of the material from which taken, and, when practicable, 12 inches long and of a width of 1½ to 2½ inches. The sheared edges will be removed to a depth of at least one-eighth of an inch, and the sides will be made smooth with a file, but no rounding of the edges will be permitted, except the removal of the feather edge. In the case of heavy ship plates of 60 pounds per square foot and over, specimens machined to ½ inch square section, center of section being halfway between outer surfaces, will be used for bends.

Treatment of test pieces.—Test pieces shall be subjected to the same treatment and processes as the material they represent and no other except machining to size. They shall not be cut off until the plate or object shall have received final treatment and shall have been stamped by the inspector, except in cases which are specially mentioned in these or in the Navy Department leaflet specifications.

Extra material for test pieces required where special treatment is given.—In the case of material which may require one or more retreatments, the objects must have attached sufficient material to enable the cutting of test pieces after each treatment. The manufacturer will be allowed only three official tests. In all cases where the test specimens fail to meet the requirements on the third test, the material represented by the specimens shall be rejected, except where the inspector recommends to the bureau concerned that further treatment or testing be authorized. In special cases general exceptions to the above may be made by the bureau concerned.

Material which may be exempt from tests.—Material called for in Navy Department leaflet specifications specified to be of ordinary commercial quality will not be subject to tests or analysis unless there is reason to doubt that it is of suitable quality. If doubt should arise as to the quality of the material the inspector may make such tests as he deems necessary to determine the quality, either at the works of the manufacturer or at the point of delivery.

Annealing.—The whole of an object specified to be annealed shall be subject to the same proper degree of heat at the same time or, when necessary, to a uniformly graded degree of heat which will produce a uniform degree of anneal. The number of hours requisite

for raising the object to sufficient temperature, the length of time during which it shall be soaked at its maximum heat, and the period for slow cooling in the furnace may be prescribed by the bureau.

Weights.—The weights of all materials shall be obtained before shipment and shall be accurately entered upon the proper invoices. Accurate standard scales which have been frequently tested shall be used, and an inspector will witness testing and weighing when possible.

Inspection stamps.—Each object accepted shall be clearly and indelibly marked with four separate stamps: (1) The private stamp of the inspector; (2) stamp of the manufacturer; (3) identification number; (4) the regulation government pass stamp. The last shall not be stamped on any material until it has been inspected and passed ready for shipment. In case of small articles passed and packed in bulk the above-mentioned stamps shall be placed on the boxing or packing material of the object. If the objects are bundled these stamps will be placed on tags securely wired to the bundles. Exceptions to the above may be made, when considered necessary, at the discretion of the inspector.

Acceptance of material.—No material will be received at a naval station, navy yard, or shipbuilding yard unless it bears, either on its surface or that of its packing, these stamps as evidence that it has passed inspection, nor shall it be finally accepted until after the receipt of a duly certified report of the inspector by whose office the inspection was made.

Rejection after having passed inspection.—Material may be rejected at a navy yard or other place of delivery for defects either existing on arrival or developed in working or storage for which the contractor is clearly responsible, even though such material may have passed previous inspection by the inspector at the place of manufacture. In such cases the manufacturer must make good any material rejected.

The following extracts quoted from the leaflet specifications give the salient characteristics of the requirements for the principal classes of structural hull material:

Specifications for Steel Plates.

Physical and chemical requirements.—(a) The physical and chemical requirements and kind of material for plates shall be in accordance with the following table:

Grade.	Material.	Minimum tensile strength.	Minimum elongation in 8 inches (*b*).	Maximum amount of— P.	Maximum amount of— S.	Cold bend.
		Pounds per sq. inch.	*Per cent.*	*Per cent.*	*Per cent.*	
Soft or flange steel.	Open hearth carbon steel.	50,000	30	0.06 acid.... .04 basic...	0.05	180° flat.
Medium steel	......do......	60,000	25	......do......	.05	For test pieces below ¾ inch in thickness, 180° flat for longitudinal; 180° to diameter of 1 thickness for transverse. For test pieces ¾ inch thickness and above, the bends will be 180° to a diameter of 1 thickness for longitudinal, and 2 thicknesses for transverse specimens.
High tensile steel.	Open hearth carbon nickel or silicon steel.	80,000	20	......do......	.05	180° to a diameter of 1½ thicknesses for longitudinal; 180° to a diameter of 2½ thicknesses for transverse.
Common steel (*c*).	Open hearth or Bessemer steel.	55,000	22	No chemical analysis required.		180° to a diameter of 1 thickness.

(b) *Elongation.*—For plates up to and including 5 pounds per square foot, the elongation shall be measured on a length of 2 inches; over 5 pounds per square foot, up to and including 7½ pounds, in 4 inches; over 7½ pounds per square foot, up to and including 10 pounds, in 6 inches; over 10 pounds per square foot, up to 60 pounds per square foot, in 8 inches.

Plates 60 pounds per square foot and over shall be measured in 2 inches, using the standard 2-inch turned specimen (Type I).

(c) Common steel may be rolled from any stock on hand, and the stamping of serial numbers on separate pieces may be omitted, provided that all other information required by these specifications, such as melt and charging records, etc., be supplied to the inspector, to enable him to select test pieces.

Two test pieces shall be taken from each melt of finished material —one for tension and one for bending.

"Common" steel plates shall, in addition to other marks prescribed, have painted conspicuously on each plate the letter "C," not less than 12 inches in height. All invoices or reports of material shipped shall be plainly marked "Common."

Physical tests—sheared plates.—(d) Plates under 60 pounds per square foot may be tested as individual plates or by melts. On "individual test" the plate is accepted or rejected on the result of the tests representing that plate only. On "melt test" all the material from the same melt is accepted or rejected on the result of the tests representing the melt, subject, however, to such special tests as may be considered necessary by the inspector.

(e) When a melt is rolled and presented for test as a melt, six plates shall be selected by the inspector for test, each plate from a different ingot, if practicable. The plates shall be so selected as to represent the topmost and bottommost parts of the ingots. When the difference in gage of the plates rolled is such that six plates will not properly represent the melt, sufficient additional plates shall be selected for test to give satisfactory information of the physical characteristics of all the gages rolled.

(f) When a melt is presented for test preliminary to rolling, six plates shall be rolled from slabs or ingots which may be selected by the inspector, each plate being from a different slab, and when practicable from a different ingot. The plates shall be selected to represent the topmost and bottommost parts of the ingots. Plates rolled for such a test shall not vary from the maximum to the minimum gage—more than 2½ pounds per square foot for plates 10 pounds per square foot and under; more than 5 pounds per square foot for plates above 10 pounds, including 30 pounds per square foot; more than 10 pounds per square foot for plates over 30 pounds per square foot. Plates subsequently rolled from such a melt shall be of the gages tested or intermediate gages, except that the inspector may authorize the rolling of gages not more than 25 per cent above and below the gages tested in the case of plates 10 pounds per square foot and under, and not more than 5 pounds per square foot above and below in the case of plates over 10 pounds per square foot. The inspector

shall satisfy himself that the material rolled has received practically the same treatment as the test plates, especially as to the amount of working, temperature during finishing, and amount of discard from the ingot.

Plates rolled to gages other than those authorized on the melt test will be tested as individuals.

(g) *Selection for "melt tests."*—One tensile test piece shall be located by the inspector on each of four of the plates submitted for test. Two of the test pieces shall be cut longitudinally, that is, in the direction of greatest working, and two transversely, that is, in the direction of least working. Two bending test pieces shall be located by the inspector on each of the two remaining plates; one test piece on each plate being cut longitudinally and one transversely.

(h) *Selection for individual tests.*—When a plate under 60 pounds per square foot is submitted for "individual test," three test pieces shall be located by the inspector. Two of these shall be tensile specimens, one to be taken longitudinally, and one transversely, one being from each end of the plate. The third test, a transverse cold bend, shall be taken from the opposite end from which the transverse tensile is taken.

When a plate 60 pounds per square foot or over is submitted for individual test, two test pieces shall be located by the inspector. One of these will be a tensile specimen, which, in plates rolled direct from ingots, will represent the material nearest the bottom of the ingot; the other will be a cold-bend specimen, which will generally be taken from the opposite end of the plate from the tensile specimen.

(i) In heat and individual tests, the specimens for tensile tests shall be required to average the requirements of the grade of steel they represent; but no test shall fall more than 3000 pounds in tensile strength, or 2 units of a per cent in elongation below the requirements for steel of the grade. An additional allowance for transverse specimens shall be a deduction of 1 unit of per cent in elongation for each increase of $\frac{1}{8}$ inch in thickness above $\frac{3}{4}$ inch; provided that the minimum elongation for any such transverse

specimen shall be 20 per cent for medium steel and 16 per cent for high tensile steel.

Physical tests—universal plates.—(j) The provisions of paragraph d, paragraph e, and paragraph f shall apply also to universal plates.

(k) *Selection for melt tests.*—One tensile test piece shall be located by the inspector on each of four of the plates submitted for test. All of the test pieces shall be cut longitudinally, that is, in the direction of greatest working. One cold-bending test piece, cut longitudinally, shall be located by the inspector on each of the two remaining plates. When plates are rolled direct from ingots, both cold-bending test pieces shall be cut from the end representing the top of the ingot.

(l) *Selection for individual tests.*—When a plate is submitted for "individual test," one tensile and one cold-bending test piece, both cut longitudinally, shall be located by the inspector. When rolling direct from ingots, the tensile test piece shall be located to represent the material nearest the bottom of the ingot and the cold-bending test piece will generally be taken from the opposite end of the plate.

(m) In tests of universal plates each specimen shall fulfill the requirements of steel of the grade.

Tolerances—permissible variation in weight and gage.—The maximum permissible variations in weight and gage, applicable to single plates, will be in accordance with the following tables:

(a) *Plates less than 10 pounds per square foot*

Weight ordered (pounds per square foot).	Allowable variation in weight (per cent).	Allowable undergauge at edge (per cent).					
		Up to 40 inches, inclusive.	Over 40 inches to 50 inches, inclusive.	Over 50 inches to 60 inches, inclusive.	Over 60 inches to 70 inches, inclusive.	Over 70 inches to 80 inches, inclusive.	Over 80 inches.
Up to 5	3 over 5 under	12	15	18	20	....	....
5 inclusive to 7½ exclusive	do	10	12	14	16	18	....
7½ inclusive to 10 exclusive	do	8	10	11	12	13	14

(b) ***Plates 10 pounds per square foot and over.***

Weight ordered (pounds per square foot).	Allowable variation in weight (per cent).	Allowable undergauge at edge (per cent).						
		Up to 66 inches, inclusive.	Over 66 inches to 80 inches, inclusive.	Over 80 inches to 90 inches, inclusive.	Over 90 inches to 100 inches, inclusive.	Over 100 inches to 110 inches, inclusive.	Over 110 inches to 120 inches, inclusive.	Over 120 inches.
10 inclusive to 12½ exclusive	3 over 5 under	10	11	12	13	14	13	......
12½ inclusive to 15 exclusive	2 over 3 under	8	9	10	11	12	14	16
15 inclusive to 17½ exclusive	do	6	7	8	9	10	11	13
17½ inclusive to 20 exclusive	do	5	5	6	7	8	9	10
20 inclusive to 25 exclusive	do	4	5	5	5	6	7	8
25 inclusive to 30 exclusive	do	3	3	3	4	5	5	6
30 inclusive to 40 exclusive	do	3	3	3	3	3	4	5
40 and up	do	2	2	2	3	3	3	4

NOTE.—(*a*) Narrow plates, or flats, intended for seam straps may be rolled on universal or bar mill and tested in accordance with requirements for universal plates.

(*b*) The use of universal rolled plates will not be permitted for butt straps or for any purpose where the transverse strength of the material is of particular importance.

Specifications for Steel Shapes.

Physical and chemical requirements.—(a) The physical and chemical requirements and kind of material for shapes shall be in accordance with the following table; all shapes shall be of uniform quality, true to section, and free from all injurious defects:

Grade.	Material.	Minimum tensile strength per square inch.	Minimum elongation in 8 inches (*b*)	Maximum amount of—		Cold bend.
				P.	S.	
		Pounds.	*Per cent.*	*Per cent.*	*Per cent.*	
Soft or flange steel.	Open hearth carbon steel.	48,000	30	0.05 acid. .04 basic	0.05	180° flat.
Medium steel.	Open hearth carbon steel.	60,000	25	0.05 acid. .04 basic	0.05	For test pieces below ¾ inch in thickness, 180° flat. For test pieces ¾ inch thickness and above the bends will be 180° to a diameter of 1-inch thickness.
High tensile steel.	Open hearth carbon, nickel, or silicon steel.	80,000	20	0.05 acid. .04 basic	0.05	180° to a diameter of 1½-inch thickness.
Common steel (*c*).	Open hearth or Bessemer steel.	56,000	22	No chemical analysis required.		180° to diameter of 1-inch thickness.

(b) *Elongation.*—For shapes, the legs or webs of which have a nominal gage $\frac{1}{8}$ inch or less, elongation will be measured in 2 inches; over $\frac{1}{8}$ inch, to and including $\frac{3}{16}$ inch, in 4 inches; over $\frac{3}{16}$ inch, to and including $\frac{1}{4}$ inch, in 6 inches; and over $\frac{1}{4}$ inch, in 8 inches.

(c)-1. *Common steel* may be rolled from any stock on hand, but all information required by these specifications, such as heat and charging records, etc., shall be supplied to the inspector to enable him to select test pieces. Two test pieces shall be taken from each heat or melt of finished material—one for tension and one for bending.

(c)-2. *Marking common shapes.*—Common shapes shall, in addition to the other marks prescribed, have painted conspicuously on each shape the word "common"; all invoices or reports of material shipped to navy yards or shipbuilding yards shall be plainly marked with the word "common."

Tests—physicial.—(Except for common steel.)

(a) *Tensile tests.*—Shapes shall be tested by lots (or singly); a lot consisting of all the shapes rolled from a particular heat at a continuous rolling into sections, the nominal gages of the webs or legs of which do not vary more than $\frac{1}{8}$ inch from the maximum to the minimum gage. Four longitudinal test pieces shall be prepared from each lot, each specimen being from a separate shape, and, if practicable, from different ingots. All of these specimens must meet the specified requirements for steel of the grade. No lot will be accepted if there is a difference of more than 10,000 pounds in tensile strength between any two of the four specimens.

(b) *Bending test.*—Two cold-bend specimens will be taken from the lot, each from a separate shape, and shall fulfill the requirements of the grade of steel without sign of fracture on the outer curve. If one of these specimens fails, each shape rolled from the lot must pass the cold-bending test before being cut to ordered length or be rejected.

(c) *Opening and closing test.*—Angles, **Z** bars, **T** bars, and other shapes, where the test is practicable, shall be subjected to the following additional test: Two test pieces will be selected at random from every 20 pieces as finished at the mill. One-half of the number of these pieces shall be closed down on themselves until the two sides touch, the other half of these pieces shall be opened out flat

while cold; and if 10 per cent or more show evidence of tearing or cracking the entire heat will be rejected unless the defect is of a local nature, in which case all of the shapes of the heat will be carefully examined and those showing evidence of similar defects will be rejected. High tensile shapes will not be required to pass the opening and closing test.

Test of a single shape.—In case of a single shape one tensile and one cold-bending test will be taken; these specimens must satisfy the requirements of the grade of steel specified.

Tolerances.—(Weight.) Shapes of 6 pounds per linear foot and less may be accepted if the weights vary between 3 per cent above and 5 per cent below the specified weight. All other shapes may be accepted if the weights vary between the specified weights and 5 per cent below them.

Steel Hull Rivets and Rivet Rods.

Rivet material.—As the efficiency of joints and hence, to a great extent, the strength of the whole structure, depends upon the rivet strength, great care is exercised in obtaining rivets and rivet materials.

Physical and chemical requirements.—The physical and chemical requirements for each grade of material shall be in accordance with the following table:

Grade.	Material.	Tensile strength (pounds per square inch).	Minimum elongation. (*b*)	Maximum amount of—	
				P.	S.
				Per ct.	*Per ct.*
Medium steel.	Open-hearth carbon.	58,000 to 68,000.	28 per cent in 8 inches; 30 per cent in 2 inches when type 1 specimen is used.	0.04	0.04
High-tensile steel.	Open-hearth carbon, silicon, or nickel steel.	75,000 to 90,000.	23 per cent in 8 inches: 25 per cent in 2 inches when type 1 specimen is used.	.04	.04

RIVET RODS.

Elongation.—For rods $\frac{1}{2}$ inch or less in thickness or diameter, the elongation shall be measured on a length equal to eight times the thickness or diameter of section tested; for section over $\frac{1}{2}$ inch and

less than ¾ inch in thickness or diameter, the elongation shall be taken on a length of 6 inches. In both the preceding cases the required percentage of elongation shall be that specified for the Type III test piece.

Type of test piece.—Type of test piece to be Type I or Type III, depending on size of rod; Type I will be used only when capacity of testing machine prevents the use of Type III.

Tensile tests.—Bars rolled from any melt shall be tested by sizes, one tensile test to be taken from each ton or less of each size. If the results of such tests from the various sizes indicate that the material is of uniform quality not more than eight such specimens shall be taken to represent the melt. In such cases the eight specimens shall be fully representative of the various sizes in the melt offered for test.

Bending tests for medium steel.—From each size of each melt one cold-bend test shall be taken as finished in the rolls, but not less than two such bends shall be made from any melt. These cold-bend specimens shall be bent 180° flat on themselves without showing any cracks or flaws in the outer round.

Upsetting tests for medium steel.—Specimens shall be cut about one and one-fourth times the diameter of the round in length, and shall be required to stand hammering down cold in a longitudinal direction to about one-half the original length of the specimen without showing seams or other defects which would, in the judgment of the inspector, tend to produce defects in the manufactured rivet.

The number of upsetting-test pieces shall equal the number of tensile-test pieces, but in no case shall it be less than two for each size.

Tolerances in diameter under the nominal gage ordered.—

Up to and including ¼ inch	.010 inch.
Over ¼ inch, up to and including ½ inch	.014 inch.
Over ½ inch, up to and including ¾ inch	.016 inch.
Over ¾ inch, up to and including 1 inch	.020 inch.
Over 1 inch, up to and including 1¼ inches	.024 inch.
Over 1¼ inches	.030 inch.

MANUFACTURED RIVETS.

Manufactured rivets, form and surfaces.—(a) Rivets shall be true to form, concentric, and free from scale, fins, seams, and all other injurious or unsightly defects. Tap rivets shall be milled under the

head if necessary. They shall conform to the dimensions and form as shown on table incorporated in and forming a part of these specifications.

Medium steel rivets, hammer tests.—(a) From each lot of rivets of each size kegged and ready for shipment there shall be taken at random 6 rivets, to be tested as follows:

(b) Three rivets shall be flattened out cold under the hammer to a thickness of one-half the diameter of the part flattened without showing cracks or flaws. Rivets of over an inch in diameter shall be flattened to three-fourths of the original diameter.

(c) Three rivets shall be flattened out hot under hammer to a thickness not exceeding one-fourth of the original diameter of part flattened without showing cracks; heat to be ordinary driving heat.

High-tensile steel rivets.—High-tensile steel rivets shall be made of rivet rods conforming to the requirements of these specifications for high-tensile steel rods and shall in addition meet the following requirements:

Shearing strength.—From each lot of each size kegged and ready for shipment there shall be taken at random 3 rivets for shearing test. These rivets shall be driven hot for test under double shear. The shearing strength when so tested shall not be less than 64,000 pounds per square inch, computed on the actual shearing area of the rivet as driven; *i. e.,* the area corresponding to the area of the rivet hole, not the nominal diameter of the rivet.

Quality test.—When for any reason the shearing test described above cannot be made, the following test shall be made: From each lot of each size kegged ready for shipment there shall be taken at random 3 rivets. These rivets shall be heated to the driving temperature, when the point shall be quickly hammered down to a thickness of $\frac{1}{8}$ inch and the rivet immediately cooled by quenching in cold water. It will then be hammered over the edge of an anvil in an effort to bend the flattened portion. The rivet shall break short without appreciable bend.

Marking and packing.—(a) Medium rivets shall be marked on top or side of head with a plain cross $\frac{3}{8}$ x $\frac{3}{8}$ inch for larger sized rivets, suitably reduced for the smaller rivets. This cross is to be in relief.

(b) High-tensile pan or button-head rivets shall have fluted heads.

(c) Unless otherwise specified, to be delivered in 100-pound boxes or kegs, marked as given below.

(d) All boxes or kegs to be strongly made and plainly marked with the manufacturer's name and contract number.

Boxes or kegs to be neatly stenciled on one end only with the net weight, size, and name of contents, as—

100 pounds
½″ x 1½″
High-Tensile Steel
Button Head Rivets.

Steel Castings.

Castings.—Many important parts of the structure of a war vessel are to-day made of steel castings, such as stem, stem post, rudder frames, shaft struts, etc. The specifications for steel castings are therefore important.

Process of manufacture.—Castings shall be made by a process approved by the bureau concerned.

Chemical and physical properties.—The physical and chemical requirements of steel castings shall be in accordance with the following table:

Class symbol.	Chemical composition. Not over—		Physical requirements.				
	P. S.	S.	Minimum tensile strength.	Minimum yield point.	Minimum elongation.	Minimum reduction of area.	Bending test; cold bend (not less than).
			Pounds per square inch.	*Pounds per square inch.*	*Per cent. in 2 inches.*	*Per cent.*	
Special....	0.04	0.04	90,000	57,000	20	30	90° about an inner diameter of 1 inch.
A.........	.05	.05	80,000	35,000	17	20	90° about an inner diameter of 1 inch.
B.........	.06	.05	*Maximum.* 80,000 *Minimum* 60,000	30,000	22	25	120° about an inner diameter of 1 inch.
C.........	.06	.05	....	....	....	....	

Class C.—Class C castings will not be tested unless there are reasons to doubt that they are of a quality suitable for the purpose for which they are intended. Tests, if required, may be made at the building yards. The inspector will select a sufficient number of castings and have them crushed, bent, or broken, and note their behavior and the appearance of the fracture.

Treatment.—(a) All castings shall be annealed. All annealing shall be done in a properly constructed pit or furnace. The furnace must be held at the annealing temperature long enough to insure that all of the interior of the casting or castings being annealed have been brought to that temperature. After the castings have been soaked at the proper annealing temperature they must be allowed to cool slowly in the furnace, carefully protected from drafts of air. Unless otherwise directed by the inspector, castings must not be removed from the furnace until they have been cooled down to the temperature at which the color dies (about 700° F.). The number of hours requisite for raising the castings to the proper temperature, the length of time during which they should be soaked at that temperature, and the period required for slow cooling in the furnace or in the air, may be prescribed by the bureau concerned if it is so desired.

Additional or subsequent treatment.—(b) Castings shall not be subjected to additional annealing or subsequent treatment without the knowledge and consent of the inspector, and when this is done the inspector will make such additional tests as will satisfy him that the re-treated castings meet the requirements.

(c) Castings that have received any treatment without the consent of the inspector shall be rejected.

Cleaning.—(d) All castings shall be thoroughly cleaned before inspection, after final treatment.

Test specimens, number, and location.—(a) Coupons from which test specimens are to be taken shall, whenever practicable, be cast on the body of the casting. The number and location of the coupons shall be such as to thoroughly exhibit the character of the metal throughout the casting. When the use of these cast-on coupons is not practicable, the test bar shall be taken from a coupon cast with and gated to the casting, or with small runners to the gate. If neces-

sary, coupons may be cast separately, but in all such cases the approval of the inspector must first be obtained. Coupons shall not be detached from the casting until it has received its final treatment.

(b) Particular care will be exercised with castings estimated to weigh 200 pounds or over that the test specimens taken from the castings shall be in sufficient number and so located as to thoroughly exhibit the character of the metal of the entire casting.

Tests, individual and lot.—(c) Castings, the estimated weight of which is 200 pounds or over, will be tested by individual tests. Other castings shall be tested by lots as follows: A lot shall consist of castings from the same heat and annealed in the same furnace charge. From each lot two tensile and one bending specimen shall be taken, and the lot shall be passed or rejected on the results shown by these specimens. Manufacturers, for their own safety, will provide enough coupons for extra tests in case of flaws showing in the test specimens.

(d) In the case of castings tested by lots, the test pieces may be taken from the body of a casting from the lot if so desired by the manufacturer. When a number of small castings have been cast on the same heat with two or more larger castings carrying test coupons, the small castings may, at the discretion of the inspector, be represented by the test bars from the large castings. A casting from which an unsound test specimen has been taken shall receive particular care to detect porosity or other unsoundness in the casting itself.

(e) A "lot" or "heat test," provided for in the preceding paragraphs, will not be permitted unless the manufacturer complies with the instructions hereafter relative to identification.

Rejection after delivery.—The acceptance of any casting by the inspector will not relieve the makers thereof from the necessity of replacing the casting should it fail in proof test or trial or in working or exhibit any defect after delivery.

Percussive test.—(a) Large castings shall be subjected to hammer tests as follows:

(b) The castings are to be suspended and hammered all over with a hammer weighing not less than 7½ pounds. If cracks, flaws,

defects, or weakness appear after such treatment, castings will be rejected.

Surface inspection.—(a) All castings shall be thoroughly cleaned and, where practicable, have the gates and heads removed before being submitted to the inspector for inspection in the green. The removal of heads and gates by burning will not be permitted. All castings shall be submitted in the green—that is, before they have received any treatment other than cleaning.

(b) Castings shall be sound and free from all injurious defects. Particular search will be made at the points where the heads or risers join the castings, as unsoundness at this point may extend into the castings.

(c) The closing of cracks and cavities by hammering and plugging will not be tolerated.

Welding, when permitted.—(d) Minor defects that do not impair the structural value of the casting may be welded up by an approved process if, in the judgment of the inspector, they are unimportant, but no such burning in or welding the defects will be permitted except after an inspection by the inspector of the casting in the green, with the defect thoroughly cleaned out to show its extent. Such welding should always be performed before annealing, and in no case shall welding be done without being subsequently annealed. The castings shall be inspected by the inspector after the defect has been welded up and before being annealed.

Chemical analysis.—Manufacturers shall furnish a chemical analysis of each heat made in an approved manner, the process of analysis to be open to the inspector. The government check analysis must show the heat to be in accordance with the specifications.

Working hull material.—In working mild steel as few heatings should be made as possible, and when heated, the material should never be worked below a red heat. As punching changes the internal character of such material, to some extent, important butt straps should be drilled or, after punching, should be annealed.

Pickling.—In the U. S. Service it is customary to pickle plates and shapes forming the structure below the water-line of the ship before working the material into the ship. This removes such of the

mill scale or rust as still remains, which, if not removed, might later peel off under the paint and flake the paint off, allowing corrosion. Mill scale is electric negative to steel and if mill scale and steel be immersed together in sea water galvanic action and corrosion occur. The material is accordingly immersed for several hours in a tank containing one part hydrochloric acid and 19 parts water. It is then removed and dipped in lime water; then washed with a hose and brushed with wire or coir brushes during washing.

It is customary in U. S. naval practice to let the balance of the steel stand unpainted in the air for a certain time, which results in a rust coating forming and loosening the mill scale. The material is then carefully brushed and cleaned before painting.

Bronzes and other materials.—Specifications are also issued covering such materials as

(a) Steel forgings such as shafting for auxiliaries, turret rollers, holding-down bolt for guns.

(b) Wrought iron for blacksmith's use.

(c) Steel bolts and nuts.

(d) Steel tubing for fire-control towers and other structural purposes.

(e) Sheet steel.

(f) Special-treatment steel for protective decks, splinter bulkheads and other places requiring superior ballistic qualities.

(a) to (e) above are not of special technical interest in a brief course and the requirements for (f) are somewhat confidential and are not quoted, but include ballistic tests at specified angles of impact.

Many important parts of modern ships are of bronze or of other material than steel. In sheathed ships such castings as the stem,

FIG. 72.—CORRUGATED METAL.

stern post, rudder, struts, etc., ordinarily of steel, are of bronze. In unsheathed ships bronze enters largely into the construction of the details of the ship, independent of the hull, and in the U. S. Service

is usually used for such items as sea chests directly attached to the hull.

Specifications are accordingly issued by the Navy Department covering a wide range of materials, such as wood, paints, etc., entering into the construction of a finished ship.

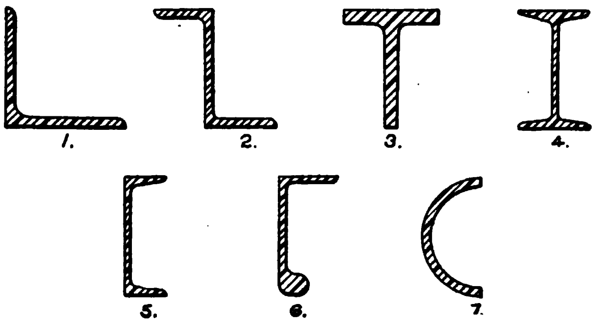


FIG. 73.—(1) Angle; (2) Z-bar; (3) Tee-bar; (4) I-bar; (5) Channel; (6) Angle-bulb; (7) Half-round (hollow or solid).

Shipbuilding shapes ordinarily used in the U. S. Service, for hull structure, are:

Plates, gaged by pounds, a plate 1 foot square and 1 inch thick being 40 pounds. A $\frac{1}{4}$-inch plate is spoken of as a 10-pound plate.

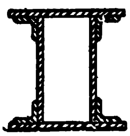


FIG. 74.—BOX GIRDER. (Box Girder made of plates and angles.)

Sheets, whose thickness is usually measured by one of the gages (U. S. standard, Birmingham wire, Brown & Sharps, etc., and spoken of as No. 12, No. 16, etc.). In U. S. naval practice the thickness of such material is by regulation now always referred to in decimals of an inch. These may be black, or galvanized, plain or corrugated sheets, *i. e.,* sheets bent so that a cross-section looks as in Fig. 72.

Shapes.—Certain rolled *shapes* (see Fig. 73), and various special shapes built up of combinations of the above shapes as Fig. 74 are used as frames, deck beams, stiffeners, bounding bars, etc.

Shapes are designated by the dimensions of flanges and the weight per foot as a $5'' \times 3\frac{1}{2}'' \times 12$ pound angle.

Referring to Fig. 73:

(1) is used for connections of plates to plates when meeting at an angle, as of bulkheads to decks, etc.

(2) is used for frames outside of inner bottom, bulkhead stiffeners, etc.

(3) is used for deck seam straps, mast seam straps.

(4) is used for bulkhead stiffeners and special fittings.

(5) is used for deck beams and stiffeners.

(6) formerly used exclusively for deck beams; lately not used at all except on torpedo craft.

(7) is used for moldings and finishings.

The proper combination of these shapes permits the maximum of rigidity and strength to be obtained for the minimum of weight.

Rivets.

In the U. S. Service the forms of rivets used are, before driving, as in Fig. 75.

(1) Pan head—with straight shank or conical neck.

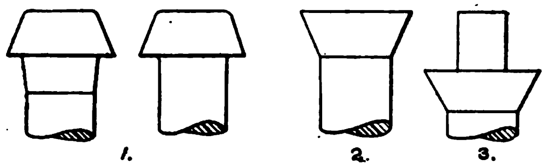


Fig. 75.

(2 Countersink head—made in various angles for various sizes of rivets.

(3) Tap rivet, or tap bolt, having a threaded shank.

These fit into holes in the plates or shapes, as in Fig. 76.

(1) Drilled; when drilled, generally made 1/16 larger than rated size of rivet when cold.

(2) Punched from side *AB;* gives a hole expanding downward. All holes in structural work on medium steel in U. S. Service are punched when material is 1 inch thick, or less; above that, drilled. All holes in high tensile steel and special steels are drilled. When

punched and fastened together ready to rivet, holes are faired by reaming, *i e.*, putting in a revolving fluted reamer, usually nowadays operated by an air drill.

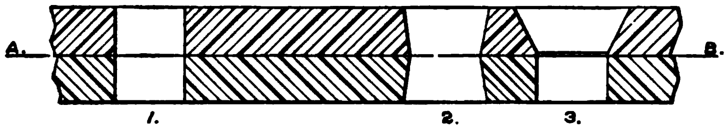


FIG. 76.

(3) Countersunk, *i. e.*, drilled out in a conical form by a pointed drill before riveting, and of such angle of cone as to take the rivet head suited for the proper thickness of plate.

Points.

The rivets, when more than $\frac{3}{8}''$, are always heated in a forge and driven hot. The end "upset" by the riveting hammer is called the ***point.*** The types of points used in the U. S. Service are as in Fig. 77.

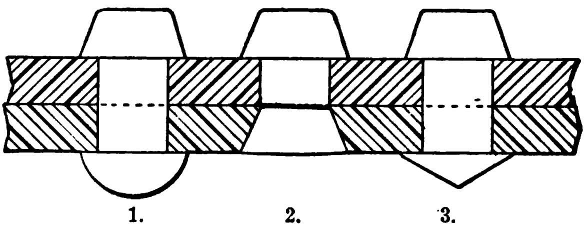


FIG. 77.

(1) *Snap* or *button,* used for work requiring finished appearance.

(2) *Flush,* generally used, and for watertight work when smooth work is required.

(3) *Smashed,* used where (1) and (2) are not desirable or necessary.

Tap rivets, having a thread on the shank, require the hole to be threaded or tapped, and are not used for through connections; they

have a square projection on the head for screwing up and this is afterward cut off. (See Fig. 78.)

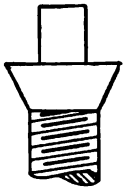


FIG. 78.

Special types of through bolts or tap bolts and machine screws are used where absolutely necessary, such as in Fig. 79.

Plates requiring to be fastened together are either lapped or butted.

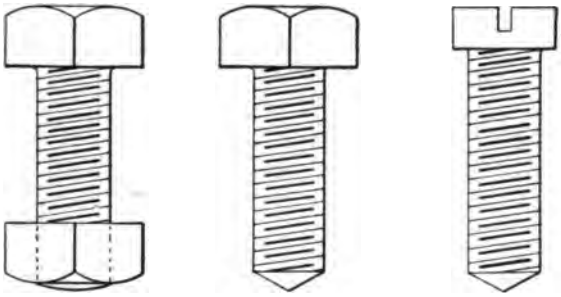


FIG. 79.

The general forms of such connections are as in the sketches given below, but the spacing and number of rows of rivets employed, *i. e.*, whether single, double, treble, or quadruple, depend on the thickness of the plates and the service to which the joint will be put.

These points are determined by various rules given in a pamphlet issued by the Navy Department called "Instructions for Riveting U. S. Naval Vessels," or calculated for each particular case to obtain the maximum strength.

Edges of plates are usually lapped, but when butted are fitted with a *seam strap.* When end-on connections of plates are to be flush, a *butt strap* is fitted. Double butt straps are sometimes fitted, in which case each strap is thinner than where a single strap is fitted.

End connections of angle bars are made by what is called a *bosom piece.* (Fig. 80.)

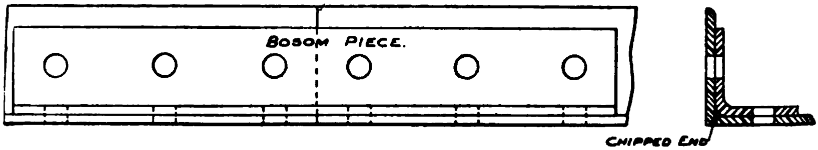


FIG. 80.

The size of rivets, the spacing of rivets in the rows, and of the rows from the edge and from each other, are important matters, and all are prescribed in detail in the riveting instructions mentioned above.

In general, centers of holes should be not less than $1\frac{5}{8}$ times the diameter of rivet from edge, and for double or treble riveting, centers of holes in adjacent rows not less than $2\frac{1}{2}$ diameters apart.

The spacing of rivets in the same row depends on the service: If watertight, the spacing varies from $3\frac{1}{2}$ to 5; oiltight, $3\frac{1}{2}$ to 4; non-watertight, 6 to 8.

Types of connections between plates are shown in Figs. 81 to 89.

Calking.

After fastening together two plates, if the joint requires to be watertight or oiltight it must be calked. If it is a butt joint, it requires butt calking, and the edges of plates must be planed. The edge of each plate near the point is split and the two edges forced together with a hollow tool. If it is a lap joint, it requires edge calking. The edge of plate is either planed or chipped and then split and forced down against the other plate.

Butt calking is not so efficient as lap calking or edge calking, being more liable to be pulled apart. (See Figs. 90 and 91.)

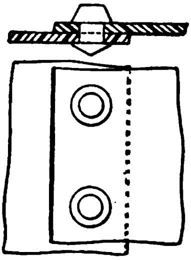


FIG. 81.—SINGLE RIVETED LAP.

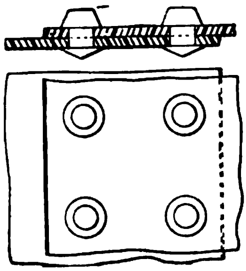


FIG. 82.—DOUBLE RIVETED LAP.

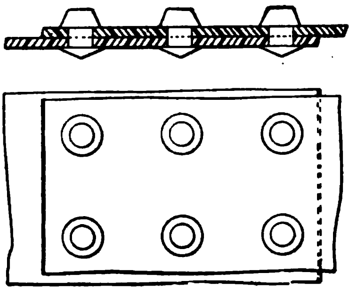


FIG. 83.—TREBLE RIVETED LAP.

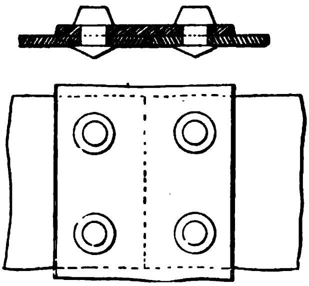


FIG. 84.—SINGLE RIVETED SINGLE STRAP.

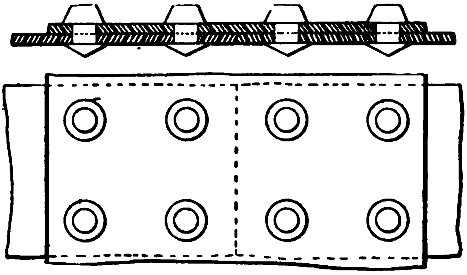


FIG. 85.—DOUBLE RIVETED SINGLE STRAP.

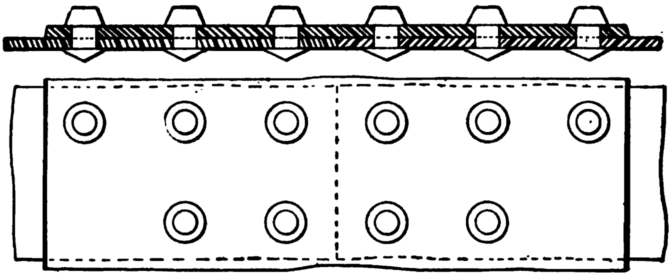


FIG. 86.—TREBLE RIVETED SINGLE STRAP.

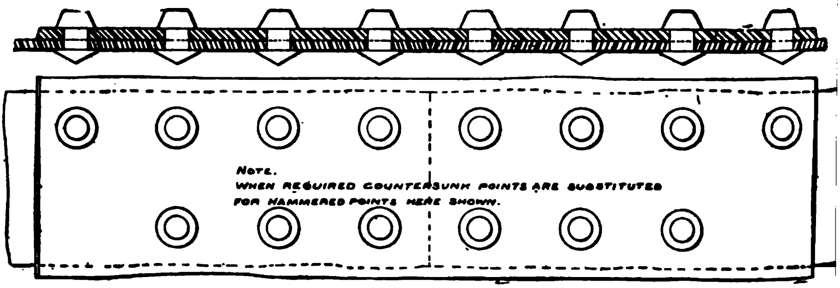


FIG. 87.—QUADRUPLE RIVETED SINGLE STRAP.

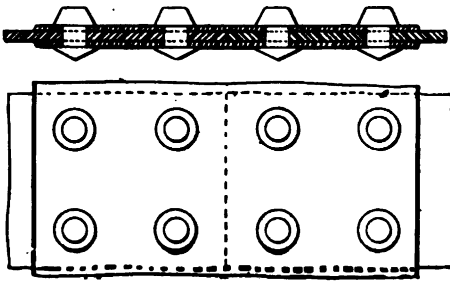


FIG. 88.—DOUBLE RIVETED DOUBLE STRAP.

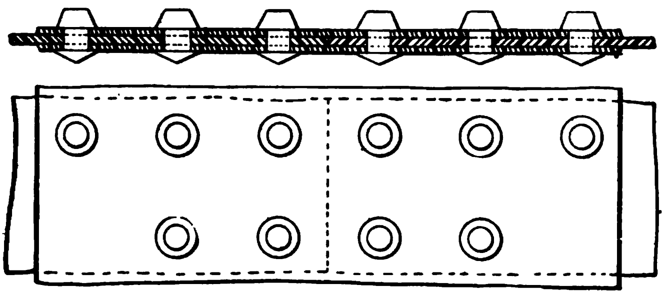


FIG. 89.—TREBLE RIVETED DOUBLE STRAP.

FIG. 89a.—LAP CALKING.

FIG. 89b.—BUTT CALKING.

NOTE.—References have been given in the text of this chapter to pamphlets issued by the Navy Department, on tests and inspections of steel material, instructions for riveting naval vessels, etc. Further information as to the general subject may be found in such engineering works as Reuleaux Constructor, and the genesis of the present naval riveting rules will be found in an article by Naval Constructor J. H. Linnard, U. S. N., in the Transactions of the Society of Naval Architects and Marine Engineers, 1896.

CHAPTER XIII.

KEELS AND FRAMING.

A navy is necessarily made up of different types of vessels to perform different functions. No attempt can be made in this book to describe exhaustively the construction of each type of vessel in the U. S. Navy. Certain main types will be treated of, and it will be seen that the intended service has great bearing on the construction of the vessel.

The student should remember that the arrangement of a ship and the distribution of material varies with the class of ship and the date of design and that no hard and fast rule as to details obtains, so that the illustrations and descriptions given hereafter are simply examples of good practice and do not pretend to cover all types or cases.

In connection with the detail description that follows the midshipman should examine the models of part-sections of ships in the model-room which show, for modern ships, the relative size and locations of the parts.

First-Class Battleships.

These ships are heavily armored and armed and have a speed moderate as compared with that of battle-cruisers and other fast cruisers. One distinctive feature, which is shared only by armored cruisers and battle-cruisers, is the provision of an inner skin up to the protective deck.

Sections of several generally distinctive types of battleships in the U. S. Service are shown in Figs. 90, 91, 92 and 93.

The inner bottom is generally about 39 inches above the outer bottom at middle line, the depth decreasing slightly towards the bilge. In our earlier ships (see Fig. 91) it was continued up to the protective deck from about the watertight longitudinal No. 5 in the form of a vertical bulkhead or wing bulkhead. In later ships it is continued to the protective deck as an inner bottom. There is, in addition, the inner coal-bunker bulkhead, so that at side and bilges

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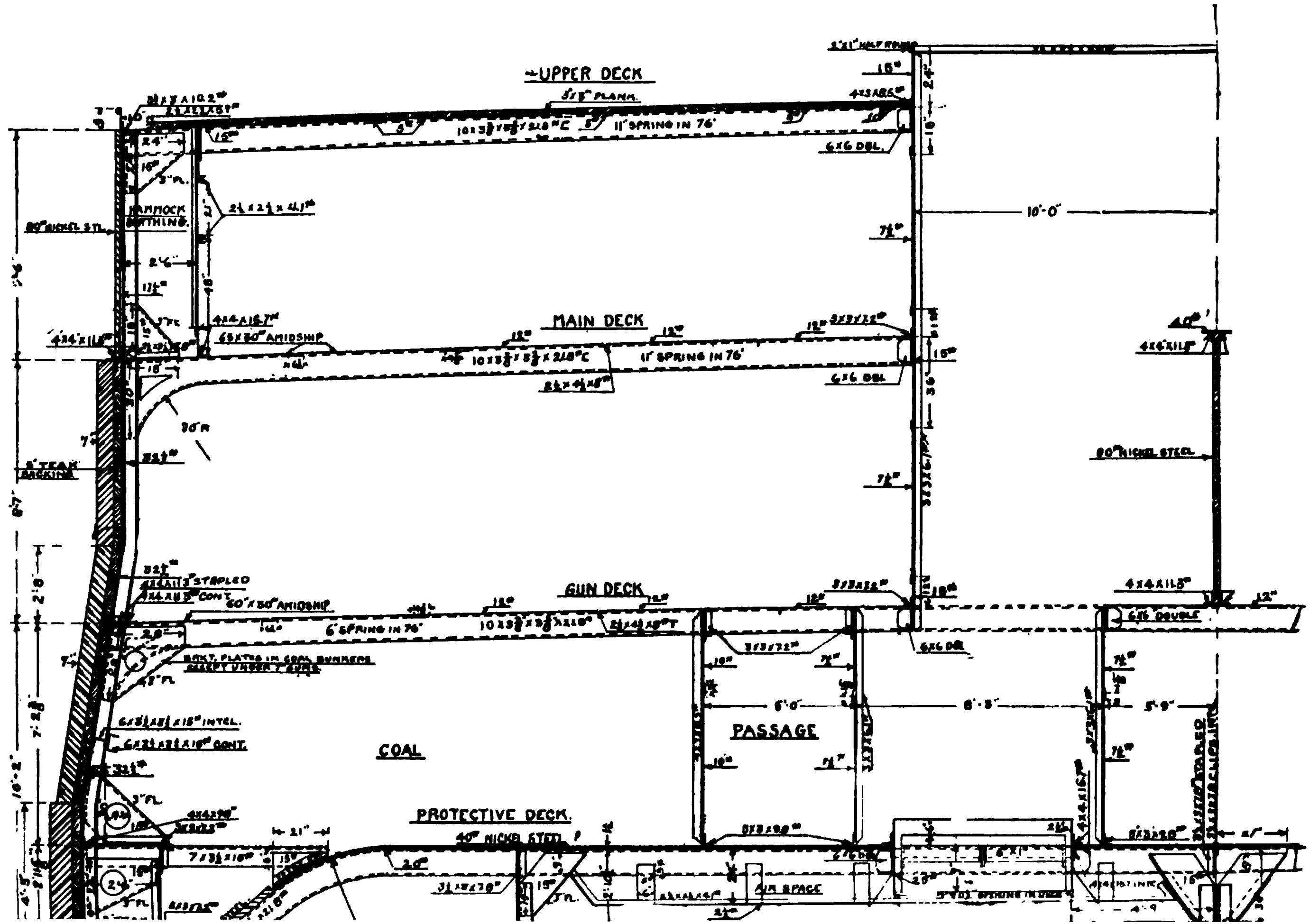
there are at least three skins to pierce before a vital part of the ship is reached. In the most recent coal-burning ships there are two longitudinal bulkheads, making four skins. In some cases the outer one of these two bulkheads is entirely without openings and is plated with special treatment steel of protective thickness. At the bottom there are only two skins, but in recent practice no ammunition has been stowed nearer the sea than the lower platform, thus giving three skins between water and explosives

A double-bottom arrangement of some form is employed in the U. S. Service for all vessels above the gunboat type in size. The inner bottom provides an inner skin in case of damage, and the double-bottom space is always subdivided by watertight floors and longitudinals into a number of watertight compartments, and so tends to localize any damage. A part of the inner bottom is generally arranged as a tank for *reserve feed water* for boilers.

In our earlier battleships, the protective deck was flat and a thick belt of armor fitted. In more recent ships, the improvement in armor permitted its general decrease in thickness and increase in area, and the protective deck was for a time made level at middle line, but sloped to lower edge of armor at the sides. In some more recent ships the thickness of armor has again increased somewhat and the protective deck is flat, and in the most recent designs two protective decks are fitted, the lower and thinner sloping to the lower edge of the armor and the upper and thicker made flat and at upper edge ot armor.

Longitudinal framing.—The main framing of a battleship is on the longitudinal system. This framing, below protective deck, consists of a continuous vertical keel and a certain number of continuous longitudinal girders on each side, generally seven, including the armor shelf on ships of the *Indiana, Kearsarge, Alabama,* and *Maine* types, and seven, exclusive of armor shelf, on ships of the *Connecticut* type. In the most recent ships of great beam this number has been increased, as it is usual not to space such longitudinals more than eight feet apart.

In our earlier battleships, the vertical keel was generally watertight, but more recently has been made non-watertight, the first watertight longitudinal generally being No. 4, though sometimes higher up. The vertical keel is 25 pounds, with two angles at bottom



UPPER DECK
MAIN DECK
GUN DECK
PROTECTIVE DECK
COAL
PASSAGE
AIR SPACE
HAMMOCK BERTHING
11" SPRING IN 76'
6" SPRING IN 76'
60"x30" AMIDSHIP
40" NICKEL STEEL
80" NICKEL STEEL
6x6 DBL.
6x6 DOUBLE
10'-0"
8'-3"
6'-0"
5'-9"

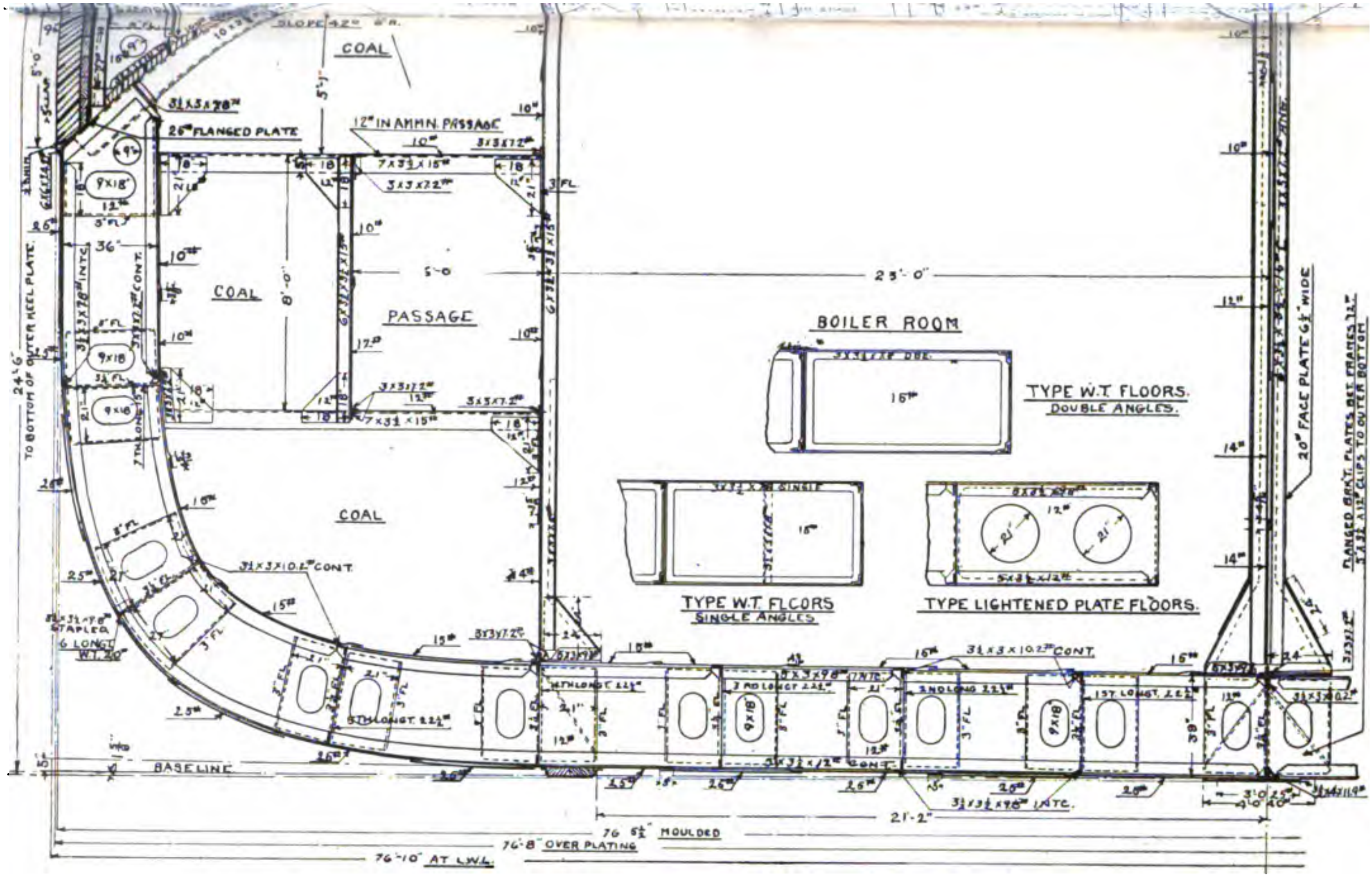


FIG. 92.—SECTION RECENT BATTLESHIP.

4″ × 3½″ and two at top 3½″ × 3″. In recent ships the vertical keel is 30 to 35 pounds, the top angles 4″ × 3½″ and the bottom 4″ × 4″. The thickness of members and sizes of bars vary with the size of the ship and are proportioned to withstand the stresses expected. These, with the middle plate of the inner bottom and the inner and outer plates of flat keel, form the backbone of the ship.

The plates of the vertical keel are connected by double butt-straps of 15-pound plate, treble riveted, with alternate rivets in outer row omitted, the straps extending between the toes of upper and lower angles. Adjacent lengths of angles are connected by bosom pieces.

The descriptive matter as to scantlings of battleship here given refers to Fig. 93 as being the latest practice. The student may, if he desires, examine Figs. 90, 91 and 92 and thus see how the practice has varied.

The longitudinals are of different thicknesses, those in the bottom 20-pound plate over about two-thirds the length of the ship, reduced at forward end to 15 pounds and at after end to 17½ pounds. The longitudinals on the side are of thinner plate. They have a single angle at bottom 3½″ × 3½″, intercostal between frames, and a single continuous angle at top 3½″ × 3″, the 3½″ flange being necessary for the ⅞″ rivets to outer bottom and longitudinal, and the 3″ flange being sufficient for the ¾″ rivets to inner bottom. These longitudinals are worked as near as possible square to the outer bottom.

The arrangement of riveting depends on whether the longitudinal is watertight or non-watertight. Non-watertight longitudinals have double-riveted lapped butts; watertight longitudinals single butt straps, treble riveted.

Watertight longitudinals have ordinarily one watertight bar and in wake of feed tanks two—one on each side—both being calked. Non-watertight longitudinals have lightening holes in each frame space where a butt does not occur, 23″ × 18″.

Sketches are given below showing—

Fig. 94.—Elevation, showing riveting, butts, angles, etc., of vertical keel.

Fig. 95.—Elevation, showing riveting of watertight longitudinal.

Fig. 96.—Elevation showing riveting of non-watertight longitudinal.

Limber or drain holes, as shown, are also provided near outer bottom for drainage.

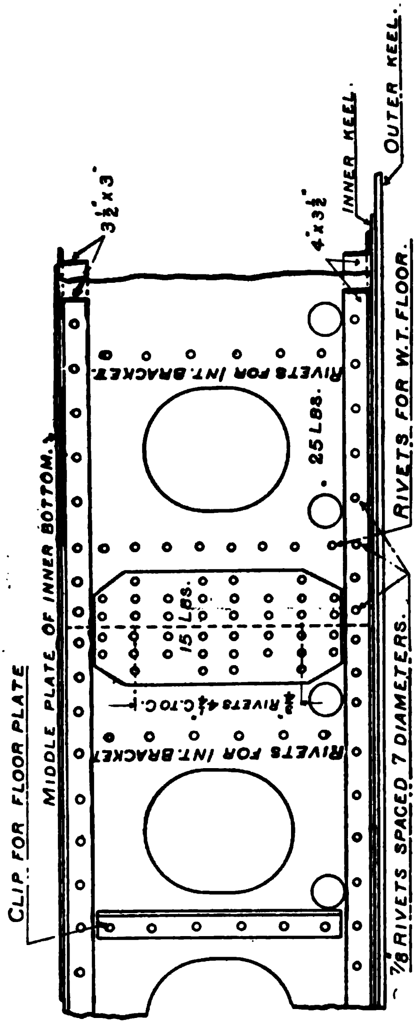


FIG. 94.—VERTICAL KEEL. Longitudinal Elevation.

The framing running transversely across the ship in the double-bottom space is worked intercostally between the longitudinals, except the outer frame bar itself. (See below.)

Adjacent frames are generally 4 feet apart.

Frames are of three types:

(1) Bracket frames.

(2) Lightened floor plates.

(3) Watertight frames.

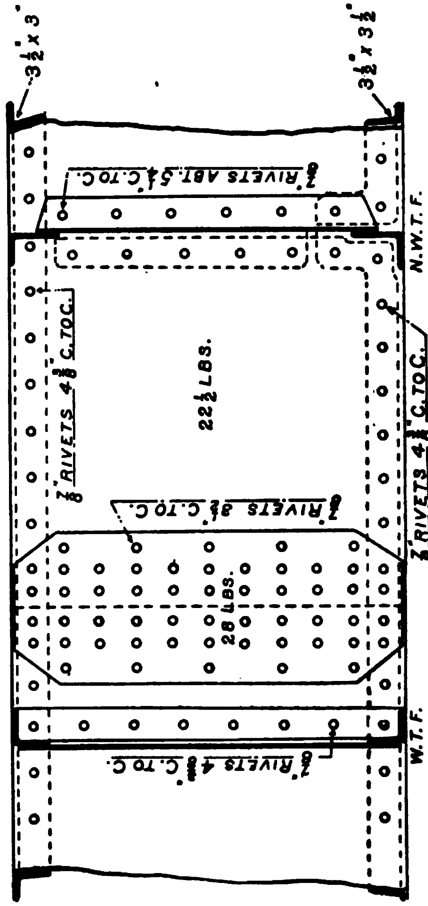


FIG. 95.—WATERTIGHT LONGITUDINAL.
Longitudinal Elevation.

Type No. 1 is, in the U. S. Service, the most numerous, being used everywhere where (2) and (3) are not used for special reasons.

Type No. 2 is used under boilers and engines and magazines where same come directly on inner bottom.

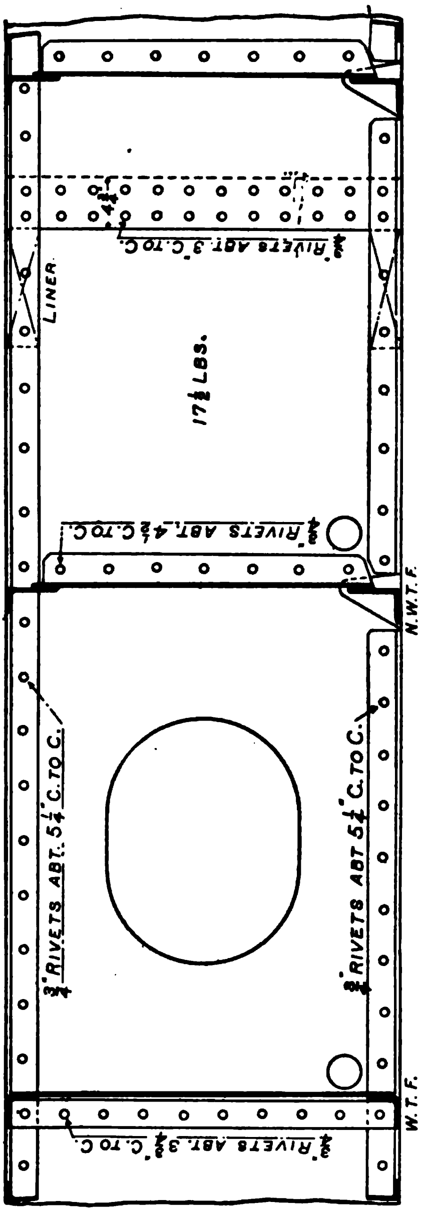


FIG. 96.—NON-WATERTIGHT LONGITUDINAL.
Longitudinal Elevation.

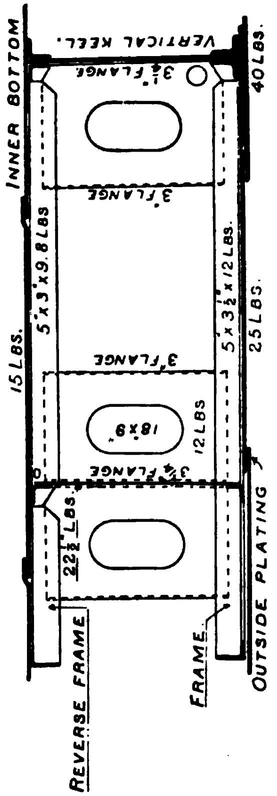


FIG. 97.—BRACKET FRAMES.
Transverse Elevation.

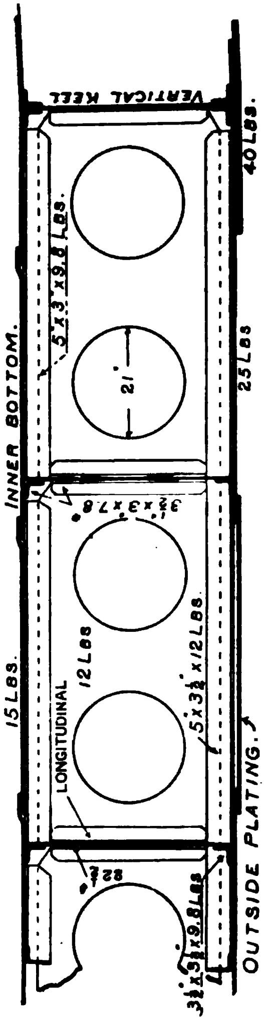


FIG. 98.—LIGHTENED FLOOR-PLATE.
Transverse Elevation.

Type No. 3 is used only under transverse bulkheads, and between these where further watertight subdivisions of the inner bottom space are needed.

In the U. S. Service the frame bar or outer bar of a non-watertight frame is continuous, the lower longitudinal bar being intercostal between the frame bars.

The bracket frame is built up as in Fig. 97.

The frame bar or bar on outer bottom is 5″ × 3½″; the reverse bar or bar on inner bottom is 5″ × 3″. To these in each space between adjacent longitudinals are riveted flanged lightened bracket plates of 13-pound plate, their inner edges stiffened by a 3-inch flange, and the edge connecting to the longitudinal having a 3½″ flange.

A lightening hole of 9″ × 18″ is cut, except where immediately over the docking keel, where this hole is omitted.

The lightened floor-plate type is built as in Fig. 98.

The frame and reverse frames are as in the bracket type. The floor plate is 12 pounds. The connections to longitudinals are by 3½″ × 3½″ bars or by flanging the edges of the plates.

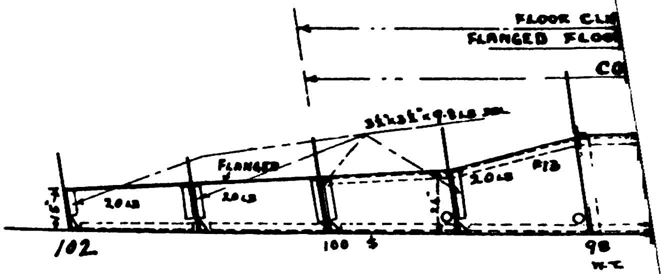
The lightening holes are 18 to 21 inches diameter, round, generally two in each space.

Stiffening angles are fitted on the floor plate where necessary, and in special cases the thickness of the floor plate is increased.

Watertight frames, with the watertight longitudinals, divide the inner-bottom space into a large number of watertight spaces. This frame is made of 15-pound plate between vertical keel and watertight longitudinal, and 12-pound plate beyond this. The plate is solid, and box-staple angles are worked around the edges and over the longitudinal bars, enabling a tight fit to be made and the whole closely riveted and calked. In wake of reserve feed-water tanks and inner-bottom oil tanks, the box-staple angles are fitted on both sides of the floor plates; elsewhere, only on one side.

Extra framing, both longitudinal and transverse, is worked under boilers and engines, if necessary to provide a rigid support.

Framing behind and above armor.—The type of framing behind armor is governed by the necessity for providing a rigid support to the armor. The amount of framing required depends somewhat



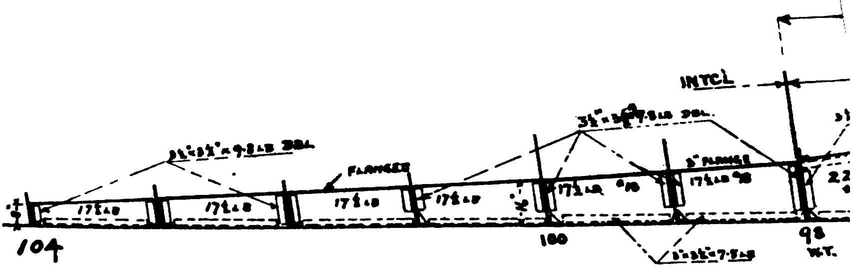
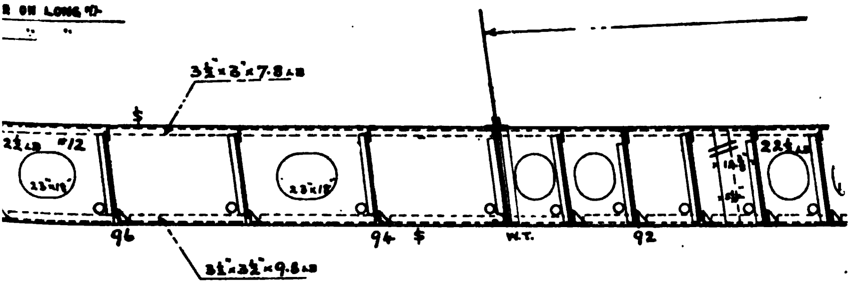
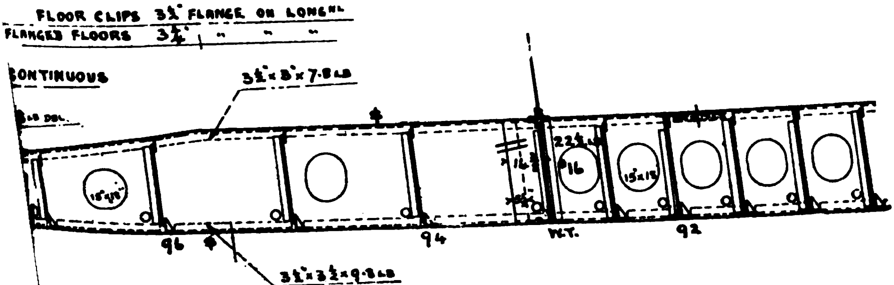


FIG. 99.—ELEVATION OF I





INALS BEYOND INNER BOTTOM.

on the thickness of armor to be supported in order to bring out its full ballistic value.

Figs. 90, 91, 92 and 93 show the development of the framing behind armor from ships of the *Oregon, Alabama, Connecticut* and *New York* type respectively.

Framing at ends of ship.—The description up to this point has dealt with the framing over length of inner bottom. The ends of the ship are somewhat differently framed.

As the bending moment in the ship as a girder has fallen off toward the ends of the ship, the question of longitudinal strength is not of such vital importance, and the main function of the framing is for supporting and stiffening the shell plating.

Here we find the transverse framing continuous from vertical keel to protective deck. The framing in a battleship is made of a $6'' \times 3\frac{1}{2}'' \times 3\frac{1}{2}''$ channel, with a 12-pound lightened floor and a reverse bar of angle section $3'' \times 3''$ worked on inner edge of floor plate and connecting to frame bar above turn of floor. The floor plate is connected to vertical keel and to longitudinals by $3\frac{1}{2}'' \times 3''$ angles, and to protective-deck beams by 15-pound bracket.

Where the frame bars pass through the platforms, the watertightness is obtained by working staple collars around the frames.

The vertical keel, as before stated, is continuous from end to end of ship, attaching to stem at forward end and to sternpost at after end. The other longitudinals, however, are altered in character at ends. As the girth of the ship decreases, these longitudinals would get very close together; therefore it is usual to stop certain of them beyond the ends of the inner bottom, tapering them down to the form shown in Fig. 99.

The others are twisted so as to attach to a flat or to a fore and aft bulkhead. This arrangement of tapering some and continuing the others is necessary to prevent any discontinuity of fore and aft strength.

At the extreme forward end, forward of the collision bulkhead, which is a bulkhead near the bow for special protection in case of collision, the frame is made of deep web plates 15 inches deep, with a $3\frac{1}{2}'' \times 3''$ angle on outer edge, and inner bounding angle of $3'' \times 3''$. (See Fig. 100.)

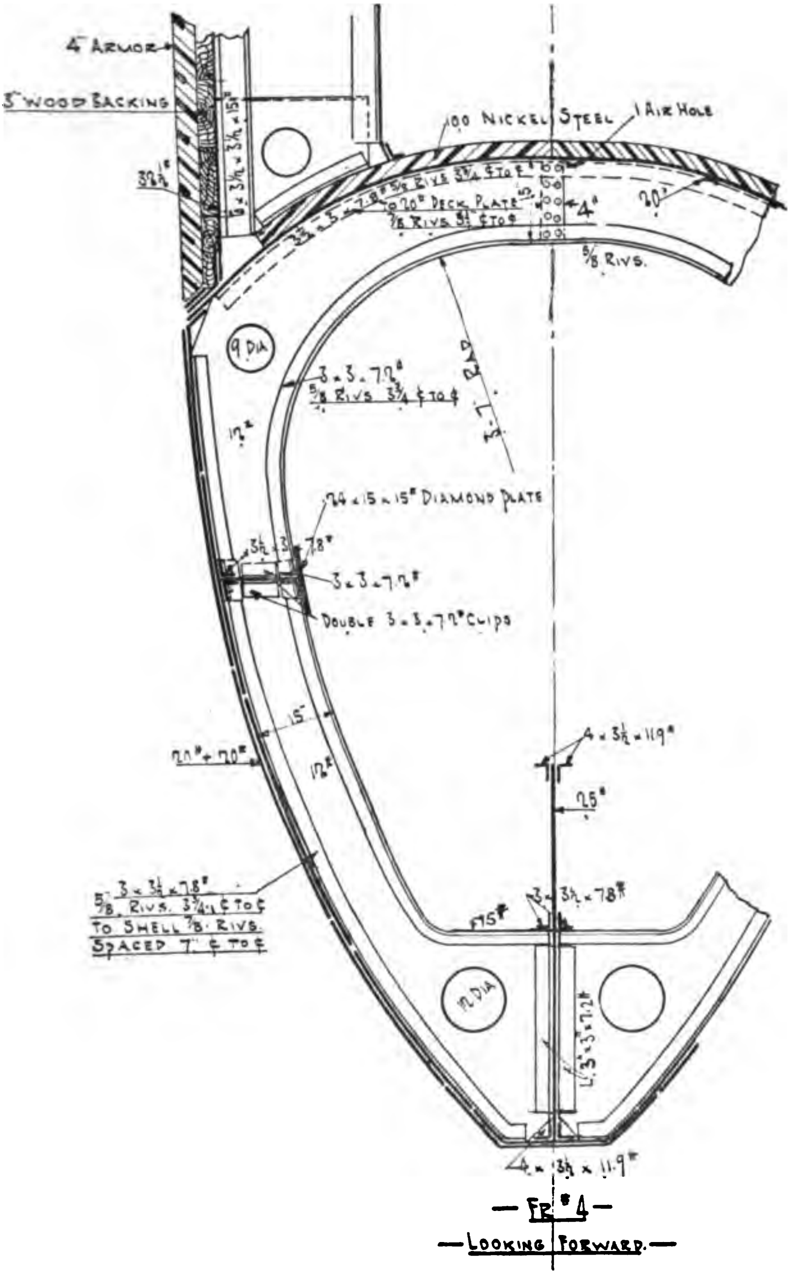


Fig. 100.—Bow Framing.
Transverse Elevation.

Armored Cruisers.

The general broad distinction between this class of vessel and battleships has been indicated before, being one of greater speed and less armor and armament. The armored cruisers in the U. S. Service exceed in displacement the earlier battleships.

The following tabular comparison indicates, in general, this distinction:

	BATTLESHIPS.		ARMORED CRUISERS.	
	Alabama.	*Connecticut.*	*Pittsburgh.*	*Tennessee.*
Length	368′ 0″	450′ 0″	502′ 0″	502′ 0″
Breadth	72′ 2½″	76′ 10″	69′ 6½″	72′ 10½″
Displacement	11,552 tons	16,000 tons	13,680 tons	14,500 tons
Armor belt	16½″ top 9½″ bottom	11″ top 9″ bottom	6″ top 5″ bottom	5″ top 5″ bottom
Armament	4—13″ 14— 6″	4—12″ 8 - 8″ 12— 7″	4--8″ 14--6″	4--10″ 14— 6″
I. H. P.	11,207	16,500	23,000	23,000
Speed	17 knots	18 knots	22 knots	22 knots

The design of cruisers classed as armored cruisers has undergone radical changes in the last fifteen years. In the *Saratoga* (*ex-New York*) and *Brooklyn,* the protection was obtained by a sloping protective deck with thick plating, with a narrow belt of thin armor near the water-line, and coal protection. (See Fig. 101.)

The *St. Louis* class, now called *protected cruisers,* have a very considerably greater protection than the *Saratoga* and *Brooklyn,* on the same displacement, as will be seen from Fig. 102.

The *Tennessee* class has a still more efficient protection of greater area, as shown, Fig. 103. Since the *Tennessee* type the U. S. Navy has built no armored cruisers, but foreign armored cruisers or battle-cruisers, so-called, of most recent date are not readily distinguishable from battleships except in having greater speed and possibly slightly less armor and fewer guns.

Taking the framing of the *Tennessee* class 502 feet long by 72 feet 6 inches beam, of 14,500 tons, we find it in principle identical

with the battleships. The vertical keel is 39 inches deep, of 25-pound plating, the top angles 4″ × 3″, and on the bottom, 4″ × 4″. The number of longitudinals on each side is the same as in the battleships. The transverse framing is substantially the same as in the battleships, both in size and arrangement. The framing in engine room is built unusually strong on account of the engine power, additional longitudinals being fitted in inner bottom in wake of engines, and intermediate transverse frames of lightened floor-plate are fitted here on the half frame spaces.

Framing of vessels of the large protected cruiser type (*Columbia*).—A typical section of such a cruiser is shown in Fig. 104. This is a type of which the U. S. Service has in recent years built none.

Here the protective deck and the coal form the protection. The inner bottom is of somewhat less extent transversely than above. The vertical keel is 42 inches deep, of 20-pound plates, with double angles at top 3½″ × 3″, and at bottom 4″ × 3″. There are 4 longitudinals on each side, 16 pounds, the fourth longitudinal being watertight, and a side stringer is worked between the W. T. longitudinal and the protective deck. The inner bottom extends from frame No. 29 to frame No. 82, about half the length. For the transverse framing within the inner bottom, the outer bar is 5″ × 3½″ angle, the reverse bar is 5″ × 3″, the floor plates being 12½ pounds, and of same general type as on battleships. At the date when this class was built, the flanged bracket floor was not in general use; otherwise the floors do not differ from present practice. From outer edge of inner bottom to protective deck, the frame is formed of an angle bar 5″ × 3½″ with reverse bar 4″ × 3½″, and a 15-pound bracket riveted in at bottom to give attachment to the W.T. longitudinal, or as it is called in merchant ship building, the margin plate, *i. e.*. a watertight longitudinal forming the outer boundary of the inner bottom or ballast tank.

Forward and aft, beyond the limits of the double bottom, the framing is of Z-bars, 6″ × 3½″ × 3½″, continuous from vertical keel to protective deck, the lower ends split and opened out, and 10-pound floor plates riveted in. Connection to vertical keel is by 3″ × 3″ angles, and the upper end is bracketed to the protective deck by

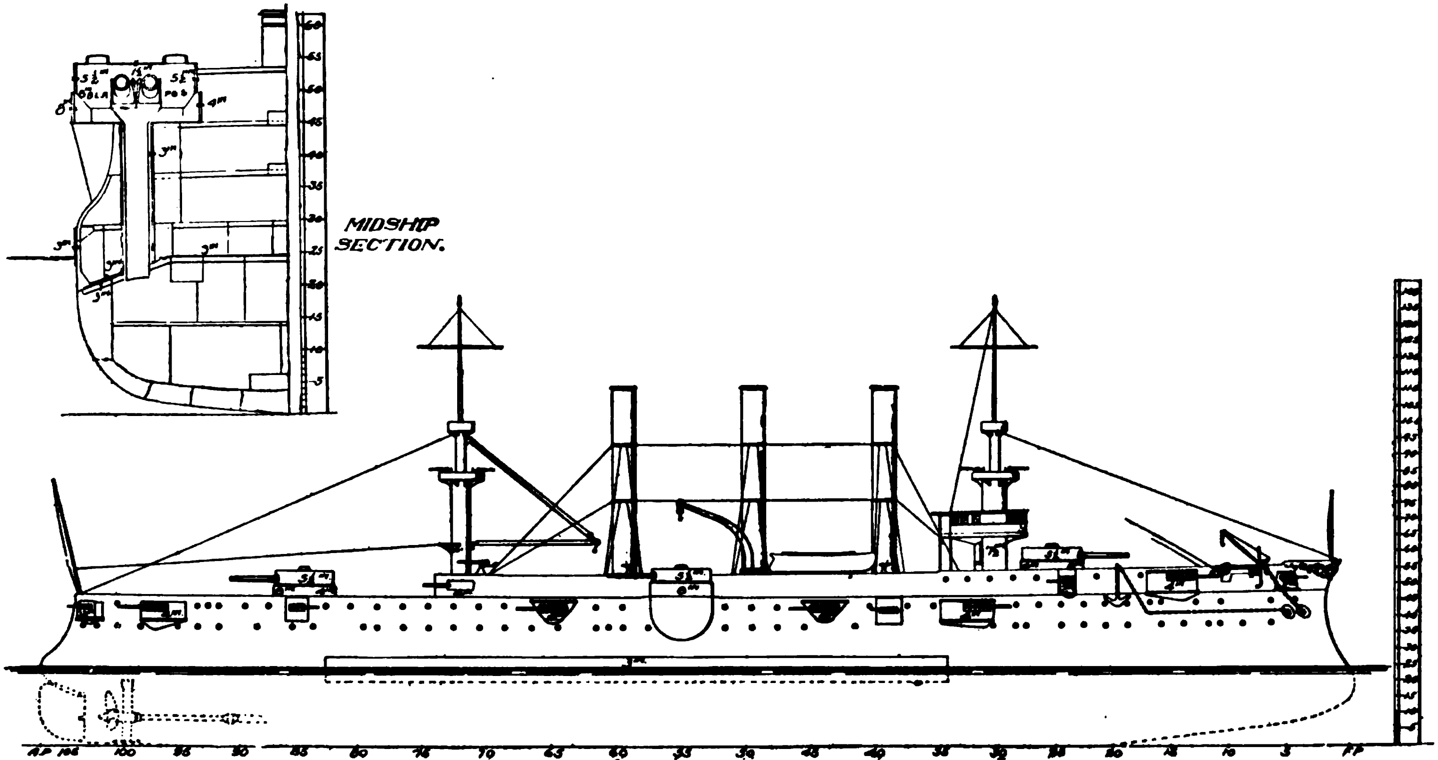


FIG. 101.—U. S. S. BROOKLYN.

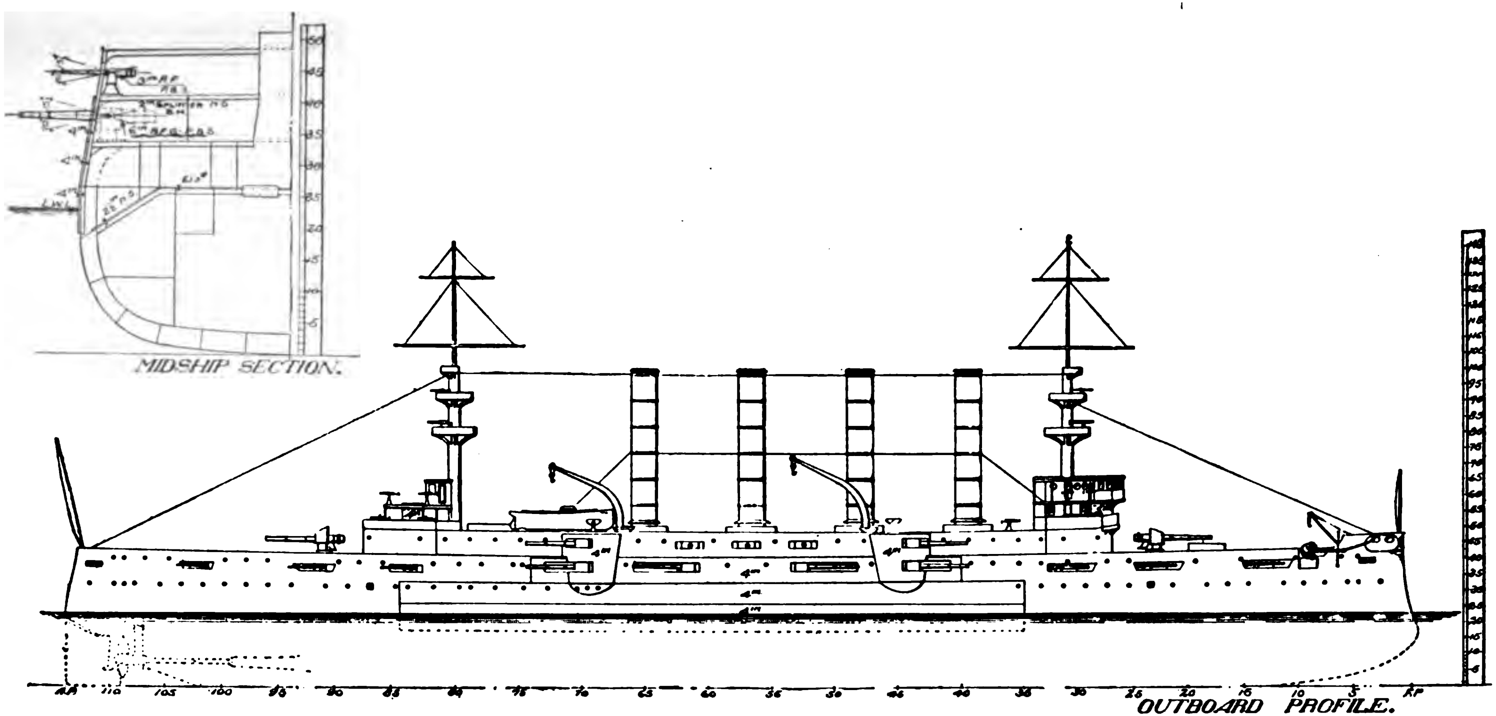


FIG 102.—U. S. S. ST. LOUIS AND CLASS.

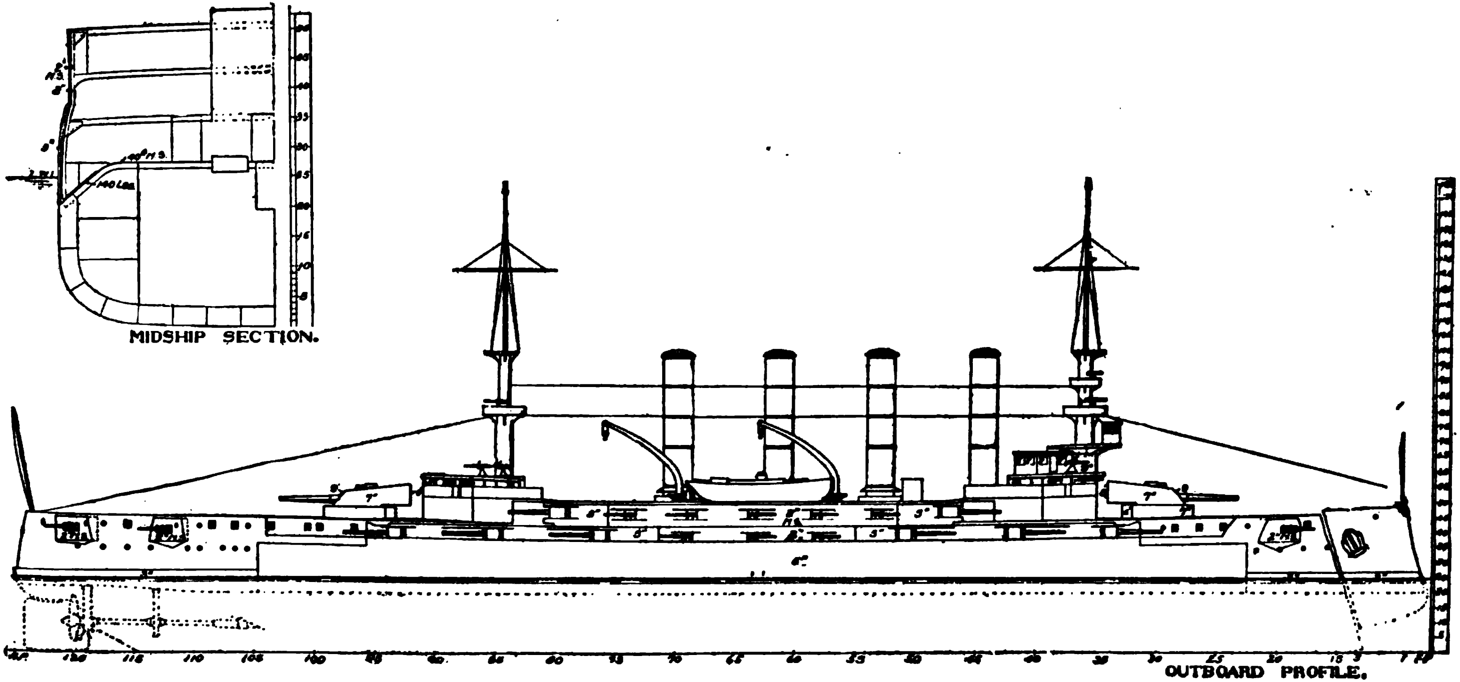
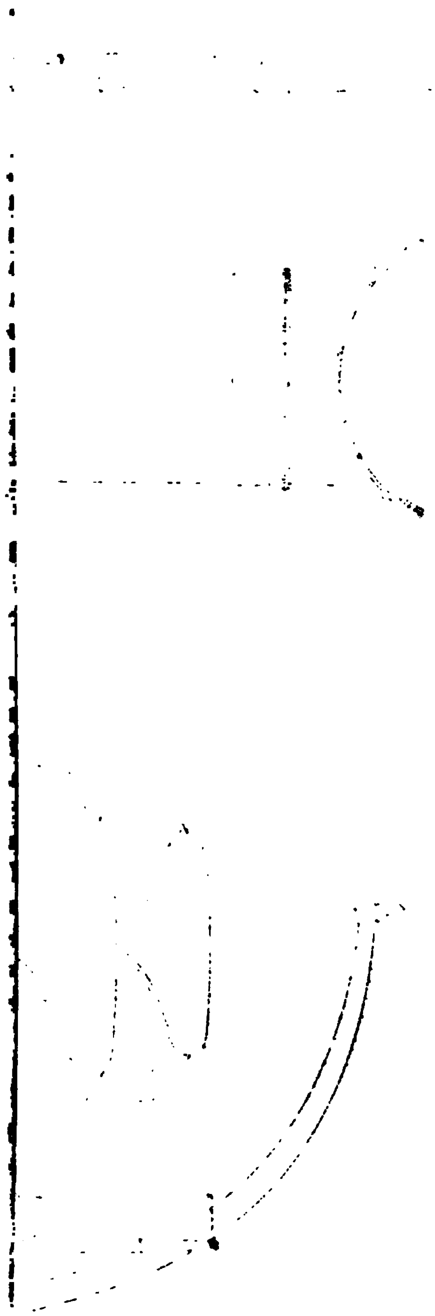


FIG. 103.—U. S. S. TENNESSEE, WASHINGTON.



15-pound plates. The framing at ends is spaced $3\frac{1}{2}$ feet. Above protective deck the framing is of $6'' \times 3\frac{1}{2}'' \times 3\frac{1}{2}''$ Z-bars in one length from protective deck to upper deck.

Scout Vessels.

These vessels, being built for special service, have special arrangements of structural features with a view to reducing hull weight to a minimum, so that it may be used for propelling power and fuel, while at the same time not sacrificing the strength of the structure. The general type of structure is as shown in Fig. 105. The vertical keel is 39 inches deep, of 15-pound plate, worked continuous and non-watertight, with double angles at bottom $3\frac{1}{2}'' \times 3''$, and at top, $3'' \times 3''$. The frame spacing is 3 feet. The inner bottom extends from bilge to bilge and over engine and boiler spaces only. The frames within the inner bottom consist of a frame bar $3'' \times 3''$ and a reverse bar $3\frac{1}{2}'' \times 2\frac{1}{2}''$. The frame bar is continuous from vertical keel to margin plate or second longitudinal. Lightened flanged bracket floors of 10-pound plate are fitted between frame and reverse bar, but under engines and boilers, lightened-plate floors are fitted instead. Outboard of second longitudinal, frames are of channels $6'' \times 3\frac{1}{2}'' \times 3\frac{1}{2}''$, continuous from bilge to main and forecastle deck, bracketed to margin plate with 10-pound lightened plate flanged and riveted to margin.

Forward and aft of double bottom, frames are $6'' \times 2\ 13/16'' \times 2\ 13/16''$ channel, split at lower end, with 10-pound plate fitted in and flanged to vertical keel. Belt frames, about 15 inches deep, of 10-pound plate, fitted on regular channel frames and stiffened on inner edge with double $2\frac{1}{2}'' \times 2\frac{1}{2}''$ angles, are worked at intervals up to platform deck, and intermediate frames are worked at half spacing in special localities.

There are two longitudinals on each side continuous, the second longitudinal being watertight.

Denver Class.

This class of cruisers, consisting of six vessels, constitutes the only sheathed vessels in the U. S. Service, except the *Severn;* they are plated with steel and sheathed with wood, and coppered, to permit

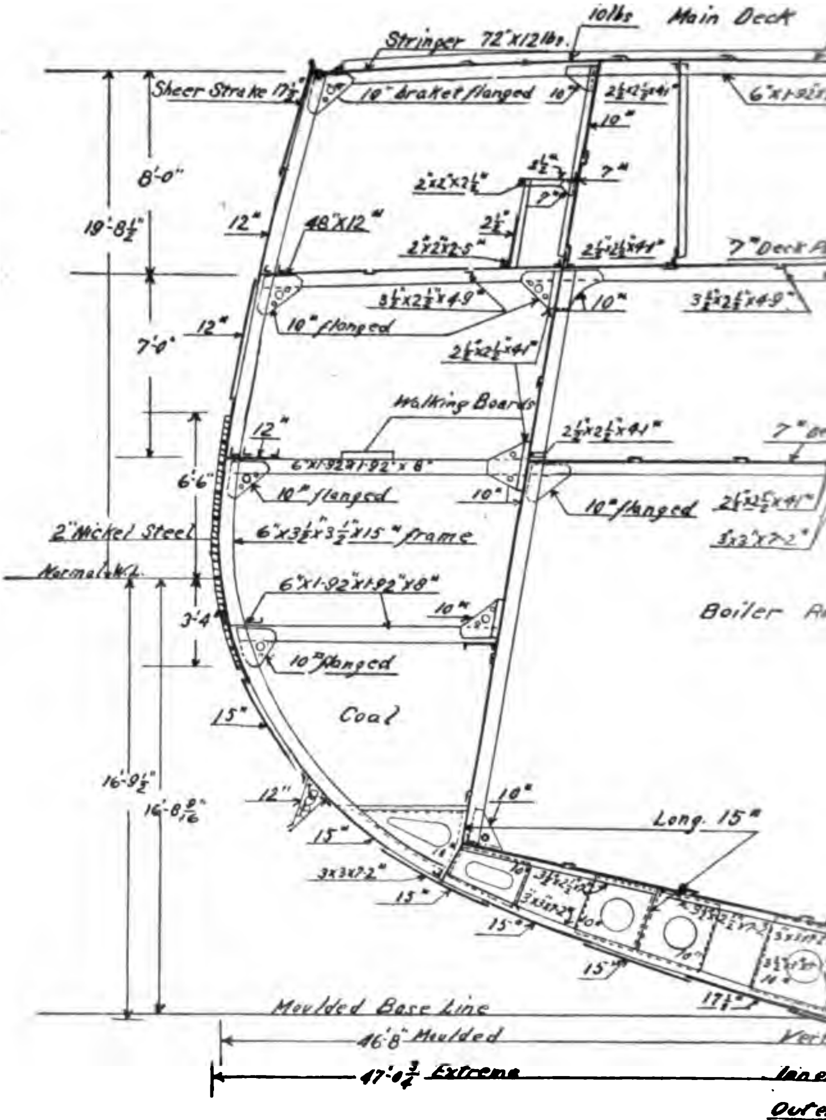
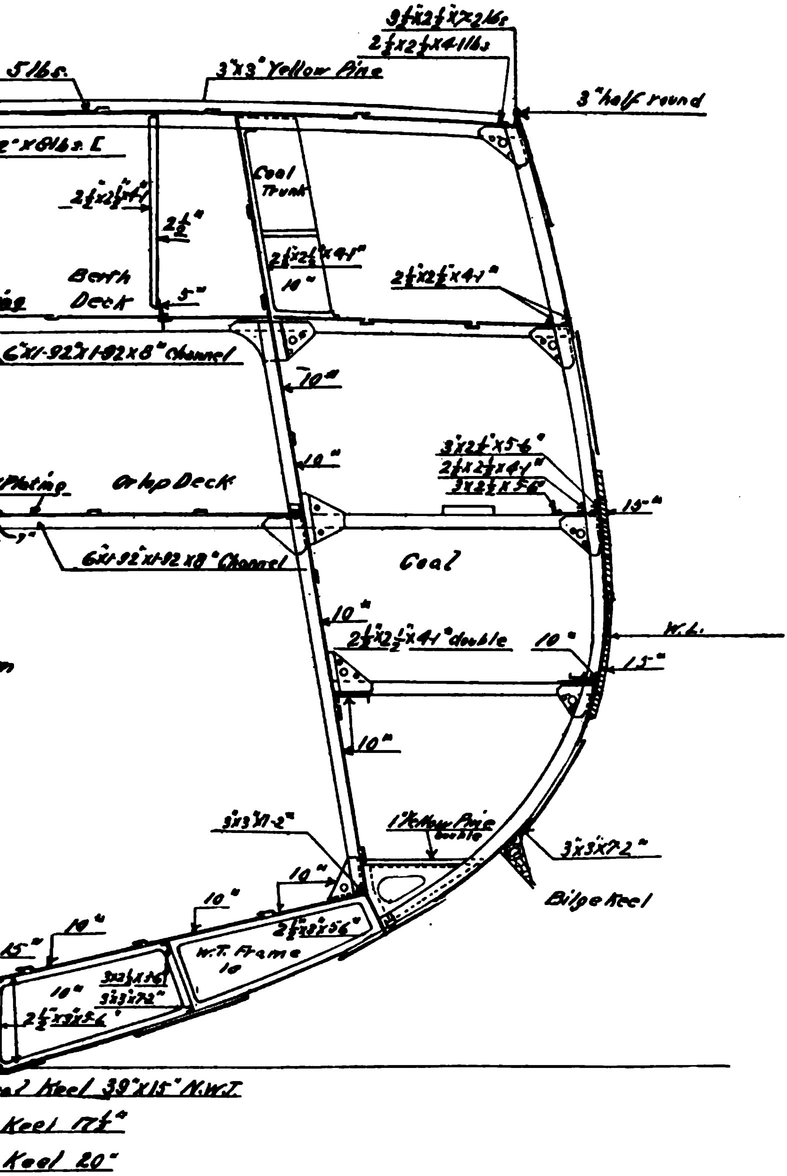


FIG. 105.—SECTIO



OF SCOUT CRUISER.

of service on foreign stations without the necessity for frequent dockings, which is necessary with unsheathed steel ships.

The midship section is as shown in Fig. 106.

Here the protective deck, coal, and cofferdams furnish all the protection. The inner bottom is retained, but is somewhat less in extent than before, being over about two-thirds of length, under magazine, engine, and boiler spaces. The inner bottom extends to the bilge on either side, as in the case of large cruisers, but there is no wing bulkhead, the coal bunker extending to the shell.

The vertical keel is continuous, 34 inches deep, of 15 pounds, with double angles at top, $3\frac{1}{2}'' \times 3\frac{1}{2}''$, and double angles at bottom, $4'' \times 4''$. There are three longitudinals on either side, two of $12\frac{1}{2}$ pounds, non-watertight, and the third of 15 pounds and watertight.

The transverse framing is of Z-bars, $6'' \times 3\frac{1}{2}'' \times 3\frac{1}{2}''$, from main deck down to and cut at turn of bilge and bracketed to margin plate. From margin plate at bilge to vertical keel, the frame bar is $4'' \times 3\frac{1}{2}''$ angle, and the reverse bar is $3'' \times 3''$ and lapping on the Z-frame bar above turn of bilge.

In double bottom, flanged bracket plates of $12\frac{1}{2}$ pounds are fitted from keel to second longitudinal, outboard of which the floor plate is of the lightened-plate type.

Watertight frames are worked as necessary for subdivision. Two longitudinal girders or bilge stringers are worked above the turn of bilge, of a continuous Z-bar $6'' \times 3\frac{1}{2}'' \times 3\frac{1}{2}''$, with intercostal plates attached to it and flanged and riveted to outside plating.

Framing at ends is of $4'' \times 3\frac{1}{2}''$ angles, continuous from keel to main deck, with reverse bar of $3'' \times 3''$ from keel to bilge.

Dubuque Class.

This class is of composite construction, *i. e.*, with metal frames and wood planking. The general features of framing the structure present no novelties. The special features of this class, such as the limited extent of shell plating, the fastening of planking to frames, and the making of plank butts, are treated in a later chapter.

The vertical keel is continuous, non-watertight, 30 inches deep, of 14-pound plate, with double angles at top, $3'' \times 3''$, and at bottom $3\frac{1}{2}'' \times 3''$. The frame spacing is 20 inches, and the inner bottom extends only under boiler room.

In inner bottom and under engine room, the frame bar is 3″ × 3″ angle, with reverse bar 3″ × 3″, and lightened-plate floors of 12 pounds, the frame, reverse frame, and floor being continuous from vertical keel to margin plate. Above inner bottom, frames are of channels, 6″ × 3½″ × 3½″, continuous to main deck, split at lower ends and bracketed to margin.

Forward and aft of inner bottom and engine room, the frames are of 6″ × 3½″ × 3½″ channels, split at lower end, and 10-pound lightened floor riveted in and flanged to keel plate. The frames are continuous to main deck.

There is no protective deck.

There are two longitudinals on either side, consisting of a continuous channel on inside of reverse frame, with intercostal pieces connecting them to shell. These intercostal pieces are of channel where depth from reverse frame to shell will permit, and elsewhere of plates riveted to the continuous channel and clipped to the shell with angles.

Special intermediate channels are worked under engine foundations.

Torpedo-Boat Destroyers.

The essential feature of this type of vessel is speed, and unusual effort is made to reduce weight to the lowest amount possible consistent with strength by use of special material and distribution of material. A section of a modern destroyer is shown in Fig. 107.

The vertical keel is continuous, 20 pounds, and about 18 inches deep, reduced to 10 pounds at forward end and 12½ pounds at after end, with double angles at bottom, 3″ × 3″, and at top, 3″ × 3″. Butts double strapped and treble riveted. The frame spacing is 21 inches. Frame bars are of angle bulb 3″ × 2″.

The triangular space shown on the right hand half of the section (Fig. 107) is an oil settling tank, these boats being oil burners.

The top and sides of this tank form bilge stringers. Where the settling tanks do not exist, *i. e.*, outside of boiler spaces, stringers or longitudinals are fitted as shown on left hand half of section.

At frequent intervals in the length of the boat, *i. e.*, at intervals of about 6 or 7 frame spaces, web frames consisting of a frame bar

2″ × 2″, a reverse bar of 2½″ × 2″ and a lightened web plate of 10 pounds are fitted as shown on left hand side of section.

On every web frame a deep beam is fitted, supported by stanchions heeled on the bilge longitudinal or settling tank edge.

The deck is supported by longitudinal girders, three on each side, continuous fore and aft.

Under boilers the floor plates are so shaped as to form boiler saddles.

The vertical keel plate and angles, the bilge longitudinals and angles, and the longitudinal girders under deck and their angles are of hard steel, *i. e.,* 80,000 pounds per square inch tensile strength. The other parts of the framing are of medium steel.

The framing and longitudinals are galvanized below the sheer strake except where within the oil tanks.

Special note should be given to the large number of lightening holes shown, to the form of bracket flanges, etc., used in the endeavor to save weight.

REFERENCES.

Specifications for various ships of the U. S. Navy.
Shipbuilding in Iron and Steel, Thearle.
Atwood's Warships, Atwood.
Constructions Pratique des Navires de Guerre, Croneau.
Practical Shipbuilding, Holms.
Cours pratique de Construction Navale, Gayde.
Cours de Construction du Navire, Callou.
Cours pratique de Construction Navale, Doyere.
Modern Shipyard Practice, McDermaid.

CHAPTER XIV.

DECKS, BEAMS, STANCHIONS, ETC.

Two systems of nomenclature have been used for the decks of United States naval vessels within recent years, prior to which still other systems obtained.

The models of part-sections of ships in the model-room illustrate the features covered by this chapter and should be consulted in connection with it. Up to 1913 the following was used, and as it still obtains on the older ships, is given here.

Steel Vessels.

1. The highest deck, extending from the stem to stern, will be called the "main deck."

2. A partial deck above the main deck at the bow will be called the "forecastle deck"; at the stern, "poop deck"; amidships, "upper deck." The name "upper deck" will also be applied to such partial deck extending from the waist to either bow or stern, in which case the name "forecastle deck," or "poop deck," as the case may be, will not be used; though the terms "forecastle" and "poop deck" may be used in a general way to designate the corresponding portions of such upper deck.

3. When there is no deck above the main deck at the bow or stern, the terms "forecastle" and "quarter deck" may be used, in a general way, to indicate the portion of the main deck forward of the foremast or of the superstructure, and aft of the mainmast or of the superstructure, respectively.

4. A partial deck above the main deck amidships, the space under which is not enclosed, or consists of small compartments, will be called the "bridge deck." This term will not be applied to a simple connecting gangway between the forward and after bridges, or between a bridge and the "forecastle" or "poop deck."

5. The working bridges will be called the "bridge," the "forward bridge," the "after bridge," the "upper bridge," the "lower

bridge," according to circumstances. A connecting gangway between the forward and after bridges or between a bridge and the "forecastle deck" or "poop deck" will be called the "fore and aft bridge."

6. The first deck below the main deck, which is used primarily for berthing purposes, and on which no guns, or light rapid-fire guns only are carried, will be called the "berth deck." This is usually the deck at or next above the water-line.

7. A complete deck on which guns are carried between the main deck and the berth deck will be called the "gun deck." If there are two such decks, then they will be called the "gun deck" and the "lower deck," respectively.

8. A partial deck below the berth deck, if located on or above the "protective deck" or the "watertight deck" will be called the "orlop deck"; if below the "protective deck" or the "watertight deck," it will be called the "platform." If there are two platforms at different levels, they will be called the "upper platform" and the "lower platform." Where no "protective deck" or "watertight deck" is fitted, the same nomenclature will be followed, the next below the berth deck being called the "orlop deck."

9. A deck of extra strength and thickness of plating worked for protective purposes will be called the "protective deck." Where such deck is stepped a complete deck height, the respective portions will be called "middle protective deck" and "forward (or after) protective deck," when it is desired to distinguish between them.

10. The deck with sloping or curved sides in smaller vessels, worked similarly to a protective deck, but not of extra strength and thickness above the structural requirements, will be called the "watertight deck."

11. A deck worked for protective purposes below a protective deck will be called the "splinter deck." This applies to a separate construction only, and not to plating worked on lower side of protective deck beams.

12. A deck that is stepped less than a deck height will be named the same as though it were continuous.

13. Deck space will, in general, take the name of the deck above which it is situated. The space above a "protective deck"

or "watertight deck" will not, however, be named from such deck, but will receive its name from the actual use to which such space is put. Thus, if the "berth deck" coincides with the "protective deck," the latter term will only be used in referring to the structural features of the deck itself, but the space above it will receive its name from the "berth deck." Similarly, an "orlop deck" coinciding with a "protective deck" gives its own name to the deck space. When neither of these decks coincides with the "protective deck," the space above the latter will be called "storerooms," "upper coal bunkers," etc., as the case may be.

Wooden and Sailing Vessels.

1. The old nomenclature will be adhered to in referring to the decks of wooden vessels and vessels with full sail power.

Beginning with 1913 and applying to all the more recent vessels the following nomenclatures of decks obtains (see Naval Instructions, Par. 2710):

1. The following nomenclature of decks shall be followed for United States naval vessels; this nomenclature will not apply to ships built, or those for which plans were completed on January 1, 1913:

2. The highest deck extending from stem to stern shall be called the "main deck."

3. A partial deck above the main deck at the bow shall be called the "forecastle deck," at the stern, "poop deck," amidships, "upper deck."

4. The name "upper deck," instead of "forecastle deck" or "poop deck," shall be applied to a partial deck extending from the waist to either bow or stern.

5. A partial deck above the main, upper, forecastle, or poop deck, and not extending to the side of the ship, shall be called the "superstructure deck."

6. A complete deck below the main deck shall be called the "second deck." Where there are two or more complete decks below the main deck they shall be called the "second deck," "third deck," "fourth deck," etc.

7. A partial deck above the lowest complete deck and below the main deck shall be called the "half deck."

8. A partial deck below the lowest complete deck shall be called the "platform deck." Where there are two or more partial decks below the lowest complete deck the one immediately below the lowest complete deck shall be called the "first platform," the next shall be called the "second platform," and so on.

9. Decks which for protective purposes are fitted with plating of extra strength and thickness shall be further defined, for technical purposes, as "protective" and "splinter," in addition to their regular names. Where there is only one such deck it shall be defined as "protective," and where there are two, that having the thicker plating shall be defined as "protective," and that having the thinner plating shall be defined as "splinter," in addition to the regular names.

10. Where a protective deck is stepped a complete deck height the respective portions shall be distinguished by means of the terms "middle protective section" and "forward (or afterward) protective section" in addition to the regular names. Where a splinter deck is stepped a complete deck height, the respective portions shall be similarly distinguished.

11. Where a portion of the protective or splinter deck is sloped, the sloping portion shall be defined as the "inclined protective deck," or "inclined splinter deck."

Beams.

The transverse framing ends at the main deck, or in ships whose quarter deck is cut down, at the main deck aft and the upper deck from the break to the bow. The upper ends of the frames are fastened together from side to side by beams. This combination of frames and beams completes the transverse structure. Beams are also introduced, tying the frames together from side to side, at the level of the various decks and platforms, and form supports therefor.

Beams for weather decks, or decks on which water is liable to come, are given a camber or roundup. For ships of 70 to 75 feet beam, this is usually 11 inches, and for small ships of 50 feet beam,

about 6 inches; for ships of beam greater than 75 feet the camber is increased beyond the 11 inches mentioned.

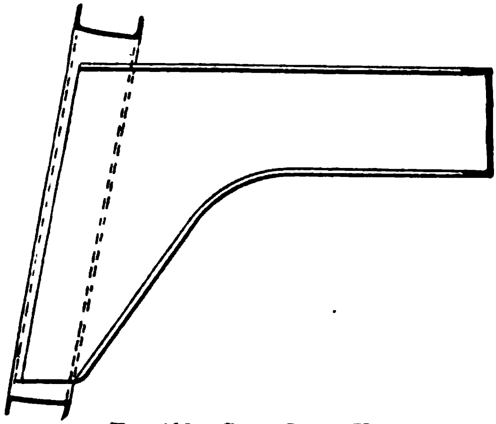


FIG. 108.—SOLID BEAM KNEE.

Beams to protective decks having sloping sides are level in the middle, and given a slope of from 30° to 40° at the side.

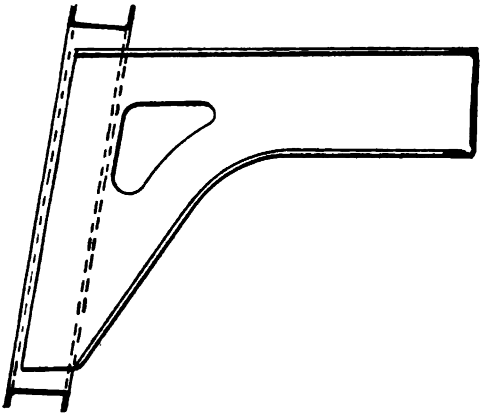


FIG. 109.—LIGHTENED BEAM KNEE.

The beam spacing for large ships in the U. S. Service is 4 feet, sometimes reduced at ends to 3½ feet or 3 feet. For scout ships and similar vessels it is 3 feet, and for torpedo-craft it is usually 21 inches. It is usual in the U. S. Service to put a beam on each frame.

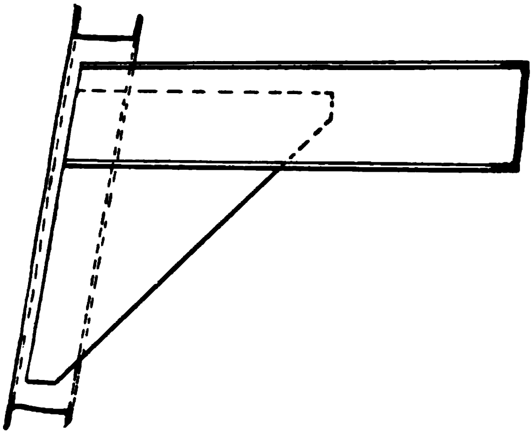


FIG. 110.—BRACKET.

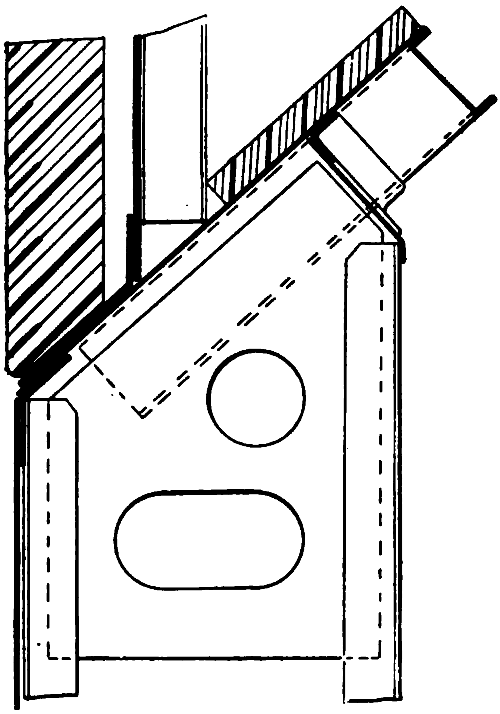


FIG. 111.—PROTECTIVE DECK BEAM CONNECTION.

Beams in the U. S. Service were formerly, for all ships, of the angle bulb section. Latterly, beginning with the *Connecticut* class, the channel section has been used exclusively, except for flats not

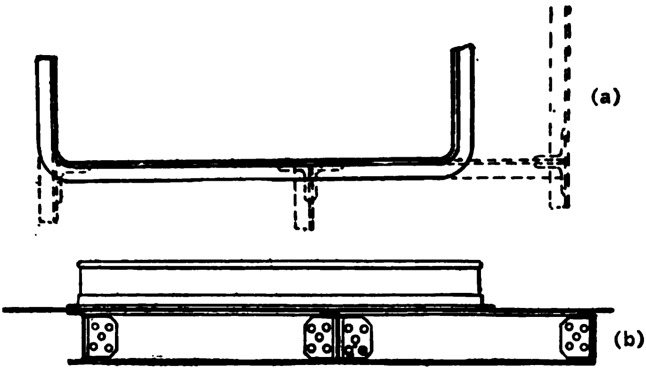


FIG. 112.—CABLING. (A) PLAN, (B) ELEVATION.

required to support much weight or water pressure, where angles are used.

The connection of the beam to the frame is of great importance, being required to withstand the racking due to rolling of the ship.

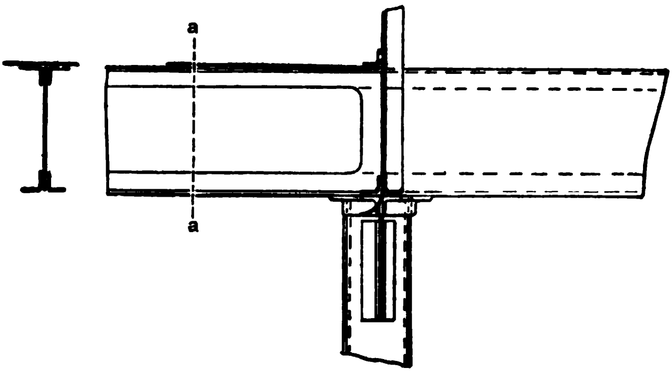


FIG. 113.—STRONG BEAM, SUPPORTED BY STANCHION.

Beams are connected to frames either by lightened beam knees, solid beam knees, or brackets. Beam knees are used where appearance is desirable, being generally lightened, except behind armor, under gun foundations and concentrated weights. A beam knee is

formed by splitting the beam at the middle of the web, and bending down the lower flange and welding in a piece of plate. Brackets are used elsewhere.

Protective deck beams are connected to inner bottom floor plates by simply lapping a good distance and riveting.

Sketches of these are given above. (Figs. 108, 109, 110, 111.)

Beams often require to be cut for hatches or other openings in the deck. The inner ends are then connected together and to the next adjacent continuous beams by fore and aft *carlings*.

Carlings are generally formed of the same section as the beams, though sometimes made of heavy plate of some depth where the opening is large, to compensate for the loss of strength, or of a heavy plate in connection with a section equivalent to the beam. (See Fig. 112.)

In the case of unusually large openings, as for cargo hatches in colliers, or for funnel openings, built-up strong beams of special section are employed and supported by stanchions. (See Fig. 113.)

Under gun foundations special beams or girders, or double beams, back to back are often employed.

Stanchions.—The beams of a broad ship, being of considerable length, require to be supported at other places than their ends. In the U. S. Service it is customary to have no greater unsupported length than 18 feet. This space is reduced where special weights or stresses are to be carried. Where possible, the ship's bulkheads are employed as intermediate supports. The vertical supports are called stanchions and are usually formed of iron pipes with solid heads and heels welded in, though sometimes of special and built-up sections, the form employed being the one to give a maximum of rigidity with a minimum of weight. (See Fig. 114.)

Stanchions are so arranged and located as to form continuous vertical supports from upper deck to protective deck or to inner bottom, the fastening of the ends being directly to the metal beam or deck, and not to plank or other deck covering which may be fitted.

Portable stanchions are sometimes fitted where interference is apt to occur, but in recent years this is seldom done.

Deck plating.—Plating is worked on decks and flats for several reasons:

(1) Contributing to structural strength, as on upper or strength deck.

(2) For protection against missiles, as on protective deck and splinter decks.

(3) To divide ship into horizontal watertight layers.

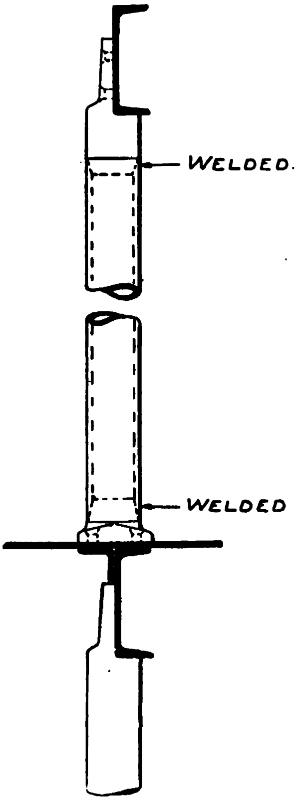


FIG. 114.—STANCHIONS.

(4) To support various auxiliaries, fittings, and structures.

(5) To protect against fire.

(6) To provide walking flats so as to best utilize the space.

Main or strength deck.—The main deck, as seen by the definition, being the upper continuous deck, is usually the strength deck, but in vessels similar to the *Alabama* and *Michigan* classes, whose

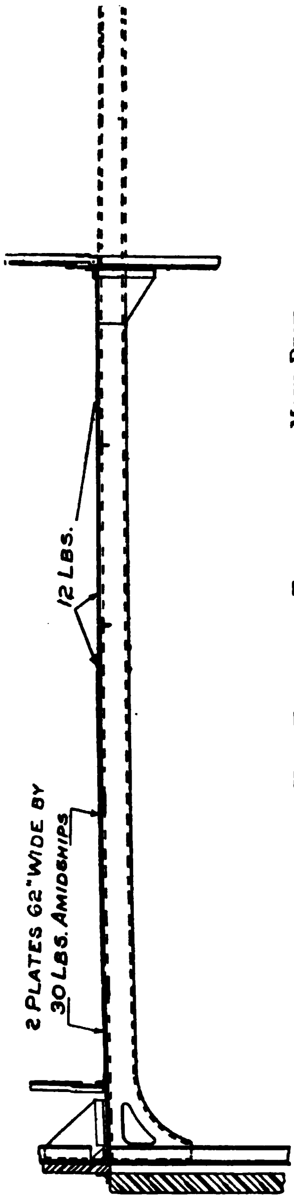


FIG. 115.—HALF TRANSVERSE ELEVATION OF A MAIN DECK.

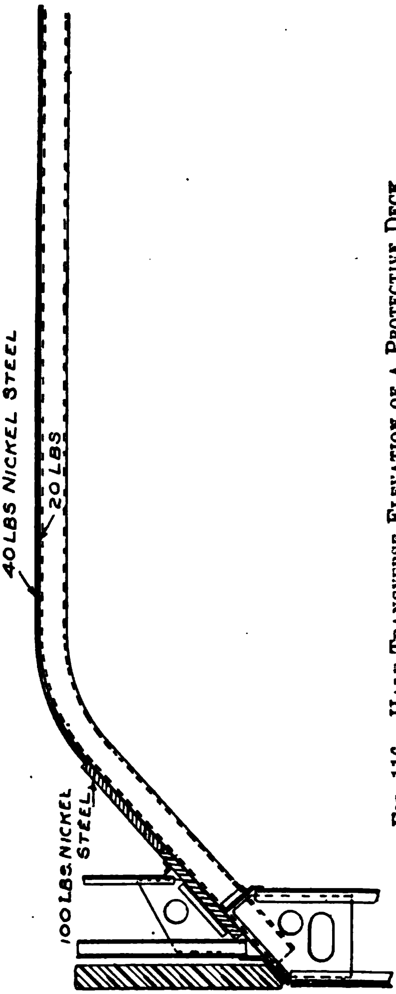


FIG. 116.—HALF TRANSVERSE ELEVATION OF A PROTECTIVE DECK

quarter-deck is lowered, the strength deck becomes the upper deck; it forms the upper flange of the girder and contributes very largely to the girder strength. (Fig. 115.)

The strake of plating at the side is called the *deck stringer*. In the deck shown in Fig. 115 it is 30 pounds, and 124 inches wide. The two outboard strakes, as in this case, are often combined to form the stringer.

Doubling plates are worked around hatch openings and other openings, to compensate for loss of strength, generally of 12 to 20 pounds, depending on location.

The weight of plating of this deck, between stringers, in general, is 12 pounds.

The plating is laid directly on the horizontal beam flanges. It generally has single-riveted edge strips on upper side for that part of deck to be later covered with wood, and T-bars worked intercostally on underside between the beams for that part to be later covered with linoleum, so as to form a flush upper surface.

For the light plating, single butt straps on under side, double riveted, are fitted. For the stringer, single straps, quadruple riveted, are fitted.

Holes for coal scuttles, deck scuttles, deck lights, etc., are carefully compensated for by doubling plates.

The butts of plates in adjacent strakes are shifted clear of one another, and particularly clear of the butts in the sheer strake.

Protective decks.—In decks fitted for protective purposes, the plating is worked in two or more thicknesses. In early ships, and up to and including the *Maine* class, this was formed of two courses of 20-pound plates, one on top of the other, and having their butts and seams so shifted that one course formed butts and seam straps of the other. On top of this was put the nickel-steel protective plating varying in thickness from 40 pounds to 120 pounds, according to location. In most of our later ships, the lower course is built like an ordinary deck, with butt and seam straps underneath and the protective special treatment steel put on top of it. In the first-named method, the two lower strakes were fastened to the beams, and the upper course fastened to them by rivets around the edges of the plates and certain tack rivets throughout its area. In the later

method, the lower course only is fastened to the beams and the upper course to it.

The general arrangement is as shown in Fig. 116.

It is necessary that there should be no openings between the upper and lower course. Therefore, after completing the structure, it is customary to pump in red lead putty to fill all existing interstices.

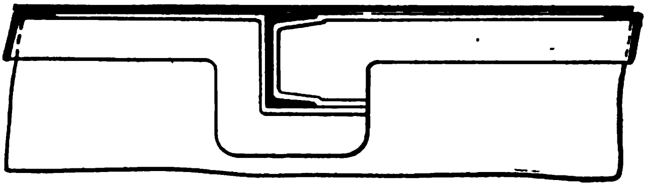


FIG. 117.—WATERTIGHT STRAPLING AROUND CHANNEL FRAME. Plan View.

Flats and platforms are generally plated with 10-pound plates and fitted with single-riveted flat seam straps and double-riveted butt straps, both worked on under side of deck to allow fair upper surface.

Special flats, as in dynamo rooms and submerged torpedo rooms, are made with ribbed or checkered plating so as to give a good foot hold.

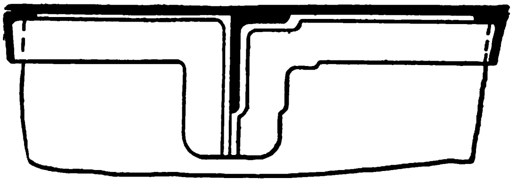


FIG. 118.—WATERTIGHT STRAPLING AROUND ANGLE FRAME. Plan View.

Watertightness of decks.—In watertight decks, the connection of the deck plating to inner bottom, bulkheads or shell plating must be watertight. The two sketches below show the method, (1st) where channel frames go through, (2d) where angle frames or stiffeners go through. As all these have to be subjected to water pressure, the work must be secure. The bars are smithed around and the riveting closely spaced and the whole calked. (See Figs. 117 and 118.)

Where transverse frames do not go through the flat, a continuous fore and aft angle can be run along and riveted and calked.

Wood decks, in the U. S. Service, are used only for weather decks, bridges, and boat decks. Formerly, wood was used for lower decks and often laid without plating. Now it is, in all cases, laid on top of plating.

Wood weather decks are, in the U. S. Service, of $3\frac{1}{2}'' \times 3\frac{1}{2}''$ long leaf yellow pine on main deck; of $3'' \times 3\frac{1}{2}''$ on upper deck, and $2\frac{1}{2}'' \times 3''$ on bridge deck when fitted, the most recent practice being to fit on bridges a form of cement. These are in some instances of teak, which, however, is an imported wood and not always obtainable.

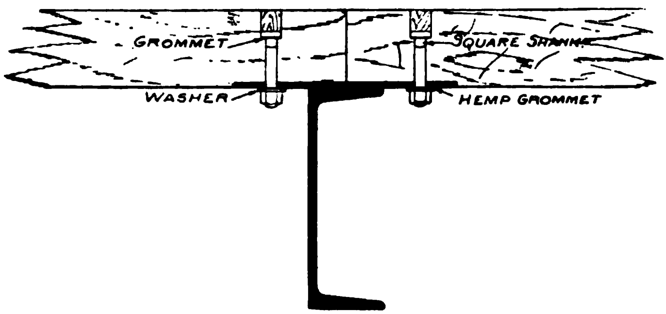


FIG. 119.—METHOD OF FASTENING DECK PLANKING WHERE THERE IS NO PLATING.

Where the deck is laid on plating, the plank is secured to plating by through bolts, two bolts in each frame space of 4 feet, and in addition, if required, by lag screws put in from underneath. In certain special cases, decks have been laid without plating, and then a strip of plate is riveted to the beam and the ends of the plank bolted to this as close to the beam as practicable. (See Fig. 119.)

Deck bolts are galvanized iron, with round head and have a square neck under the head; they are $\frac{5}{8}''$ or $9/16''$ in diameter, depending on thickness of plank; they are fitted with a grommet under head, soaked in white lead, and also under washer at point. The head is recessed in a round hole and the hole filled with a plug bedded in white lead, the grain of the plug running in same direction as that of plank.

The planks before laying are slightly outgaged and the seams calked with (for main deck) four threads of oakum, forced down

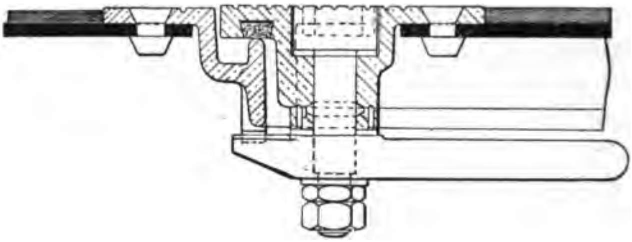


FIG. 120.—EDGE OF FLUSH WATERTIGHT HATCH SHOWING FASTENING.

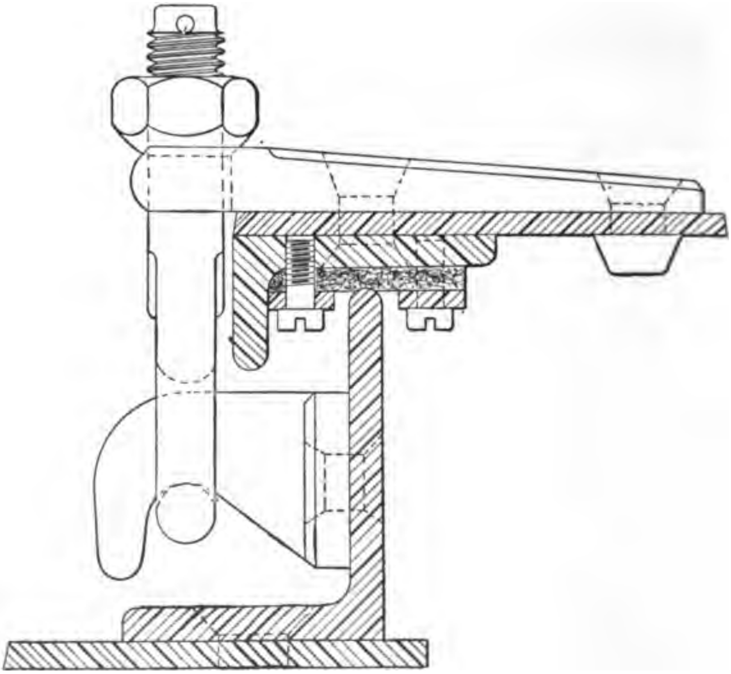


FIG. 121.—EDGE OF RAISED WATERTIGHT HATCH SHOWING FASTENING.

into the seam leaving a seam $\frac{3}{4}''$ deep, which is then payed with marine glue.

In living spaces, linoleum is fitted, the steel deck under being kept flush for this purpose. This is fastened down with glue.

Around edges, this linoleum is fastened by brass strips screwed to plating. In galleys, bath rooms, wash rooms, etc., tiling is fitted, bedded in Portland cement about 2″ deep.

In wake of doors, at foot of ladders, etc., non-slipping treads of lead and bronze are fitted. In special places, rubber tiling, wood gratings, and other special coverings are fitted.

The *hatches* in ordinary decks are of two types—flush, or raised.

Figs. 120, 121, show these types in the U. S. Service.

Care should be given to rubber gaskets used for purposes of watertightness, and no paint should be allowed to touch the rubber. When the rubber is hard, it should be renewed.

NOTE.—For references to this and succeeding chapters on structural work, see those given at end of Chapter XIII.

CHAPTER XV.

OUTSIDE AND INNER BOTTOM PLATING.

NOTE.—In connection with the study of this chapter, the midshipman should examine the models in the model room.

Outside bottom plating.—This is the most important part of the structure, contributing largely to the structural strength and insuring watertightness and hence the flotability of the hull; it also forms a considerable portion of the weight. The advantage of making the outer bottom of mild steel comes from its ductility, permitting considerable deformation by grounding or shock without fracture.

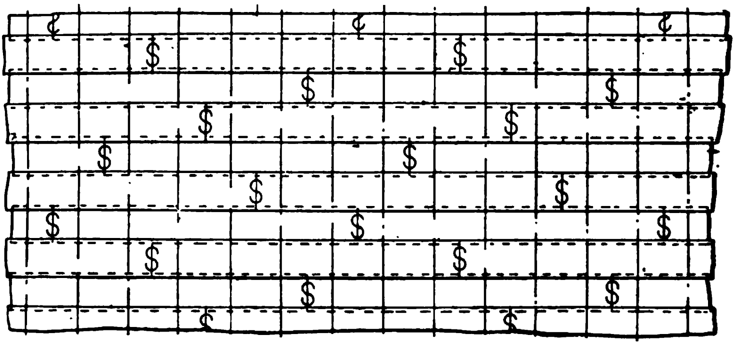


FIG. 122.—SHIFT OF BUTTS.

Shift of butts.—It is important in connection with the longitudinal structure of a ship to arrange for a good *shift of butts.*

A butt, *i. e.,* the end connection of two plates, is a place of relative weakness, and butts of the adjacent strakes and of the various portions of the structure should be kept well clear of one another. For shell and inner bottom plating, butts are not permitted to fall in the same frame space oftener than every fourth strake, except at the ends of the ship, where, owing to decrease in girth, it becomes necessary to drop some strakes and where the decrease in stress does not make it a matter of such great importance. As it is now practicable to obtain and work steel plates 20 feet to 24 and 28 feet long, this requirement is not too onerous. With a 24-foot plate it is possible, in 4-foot frame spacing, to get five passing strakes between butts in the same frame space (Fig. 122).

This principle should also be borne in mind in arranging butts of vertical keel, longitudinals, etc., to avoid weakness of structure.

Plating of a battleship.—The outer bottom plating of a battleship is usually made 25 pounds for about three-fifths of length, reduced to $22\frac{1}{2}$ pounds at end.

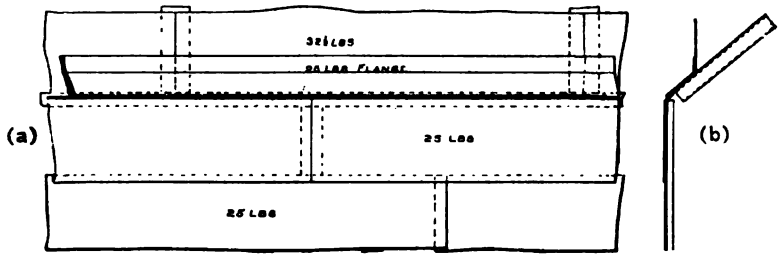


FIG. 123.—OUTER BOTTOM PLATING, NEAR ARMOR SHELF.
(a) Elevation. (b) Transverse Section.

The fore and aft rows of plating are called *strakes*. In the same strake, the ends of these plates are lapped and treble-riveted, ex-

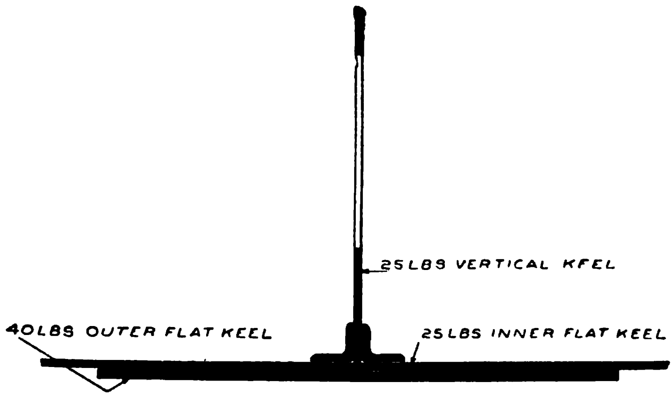


FIG. 124.—KEEL.
Transverse Section.

cept the strake next below the protective deck, which is fitted with a single 30-pound butt strap inside, treble-riveted, with alternate rivets in outer row omitted.

The adjacent strakes are worked on the *raised* and *sunken* system, the laps being double-riveted (Fig. 123).

At every frame in way of outside strake or raised strakes, a liner is fitted to get good riveting between frame and plate.

At middle line, an additional outside plate is worked, called *outer flat keel,* the inner plate being the *inner flat keel* (Fig. 124).

Riveting in outer bottom.—In Fig. 125 there will be seen, in some detail, the riveting, etc., in the outer bottom near middle line.

The lower angles of the vertical keel are connected to flat keels by 1-inch rivets. In the U. S. Service the vertical keel is not watertight; therefore, these rivets are spaced 7 to 8 diameters.

In the ship shown the longitudinals standing perpendicular to the outer bottom are not watertight, except No. 6, which is watertight throughout, and Nos. 3 and 5, which are watertight over a part of their length only, to form boundaries for reserve feed-water tanks. At ends where the girth is reduced, the watertightness is sometimes shifted from No. 6 to some other longitudinal.

There is of course no fixed rule as to which longitudinal shall be watertight, this being determined to best suit the conditions in each design.

Where longitudinals are watertight, close spacing for the rivets in their bounding angles is necessary.

The butt straps of inner and outer flat keels extend from keel angle to edges of plates connected, and are treble-riveted, with alternate rivets in outer row omitted. Size of rivet, $\frac{7}{8}$-inch for straps of inner keel, and 1-inch or $1\frac{1}{8}$-inch for straps of outer keel.

The edges of the inner keel plate are single-riveted to outer keel plate, and the edge of the outer keel plate is double chain riveted with $\frac{7}{8}$-inch rivets to the garboard strake, *i. e.,* the next adjacent strake to the flat keel.

The remainder of the shell riveting is with $\frac{7}{8}$-inch rivets.

At the butt laps of plates in inside strakes, taper liners are fitted in the seams (Fig. 126).

The ends of the plates if not lapped are butted and fitted with single butt straps, double-riveted for inside strakes, extending the full width of plate; for outside strakes, extending from edge to edge of adjacent inside strakes.

The ordinary frames are connected to the shell plating by $\frac{7}{8}$-inch rivets, spaced 8 diameters, but for watertight frames this spacing

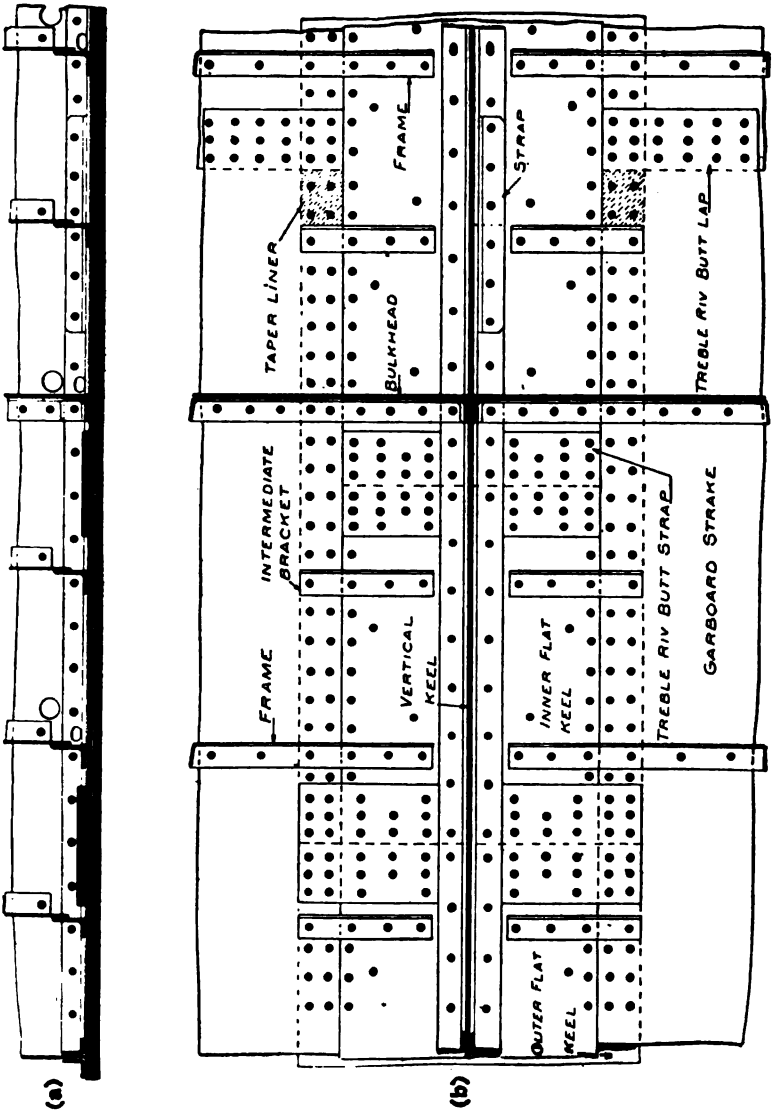


FIG. 125.—RIVETING IN OUTER BOTTOM.
(a) Longitudinal Section. (b) Plan.

is 5 diameters. This close spacing cuts away considerable material and it is customary to compensate for this by fitting on the raised

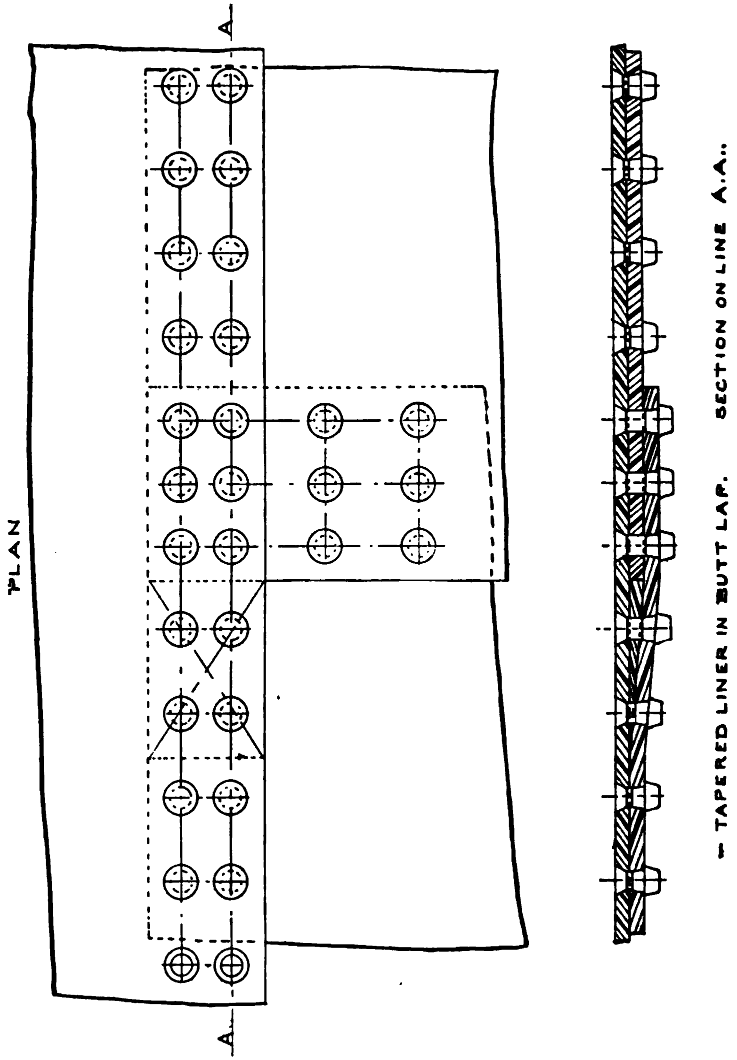


FIG. 126.—TAPERED LINER IN BUTT LAP.

strake a lozenge or bulkhead liner, by which the strength is brought up to that of an ordinary frame. Where a watertight frame comes

next to a butt strap, the butt strap is usually extended to form a liner. Fig. 127 shows a combined bulkhead liner and butt strap.

Plating behind armor.—Above the protective deck the side plating is recessed back from the side of the ship to allow for fitting armor and backing without having a projecting overhang (see Fig. 91).

This plating is made of 32½ pounds behind armor. Above the armor, where the armor stops short of main deck, and beyond it, at

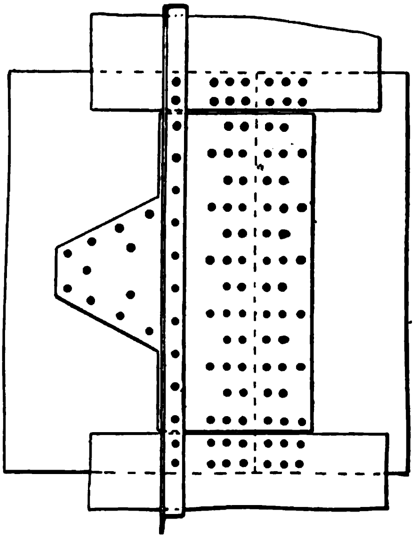


FIG. 127.—BULKHEAD LINER.

ends, the plating is reduced to 20 pounds, except where greater thickness is required for strength. Behind armor, this plating is worked close against the frames, with double-riveted continuous-seam straps on the outside. The butts of this plating have 40-pound straps on the inside, quadruple-riveted, with alternate rivets in outer row omitted. Above the armor and beyond the ends of the armor, the plating is worked with continuous seam straps on inside, double-riveted, with liners fitted between the straps in wake of frames.

Doubling plates are fitted in wake of hawse pipes and anchor beds, in wake of all holes for sea chests, etc., forward, for chafe of anchor chains, and aft in vicinity of sternposts.

Inner bottom.—The inner bottom of a battleship is generally of 15-pound plate below the watertight longitudinal, and 10 pounds above. The middle plate or keelson plate is 15 pounds also. In our earlier battleships, up to and including the *Maine* class, this inner bottom extended to the 5th longitudinal, and was then continued up to the protective deck by a vertical bulkhead called the *wing* bulkhead. In our later battleships, the inner bottom has been made continuous to protective deck.

It is important to have convenient access to all parts of the inner bottom space, for inspection, cleaning, etc. It would be best to have two manholes at opposite corners of the inner bottom compartment, but owing to obstructions everhead, this is generally not possible.

A sketch of an actual arrangement is shown (Fig. 128).

Manholes, as fitted in the U. S. Service, are one of two standard types—low coaming or high coaming—as shown in sketches (Fig. 129).

At some other places, as on cofferdams and bulkheads, where occasional access only is necessary, the edge of the hole is fitted with a ring and stud bolts, and a portable plate is secured by nuts on these studs (see Fig. 130).

All inner bottom spaces are tested under water pressure, in building, to a head of 35 feet above bottom of keel, and if the test is not satisfactory, the defects have to be made good and the compartments retested.

For vessels of the armored cruiser type, the plating is nearly identical with that for battleships, both in thickness and arrangement, and therefore no special treatment of the subject is given here.

Outer bottom and inner bottom of large cruisers of *Columbia* type (400′ × 58′ × 7400 tons):

This plating is arranged on same principle as for battleship, but the thickness is generally somewhat less, the outer flat keel plates being 25 pounds, inner keel plate 22½ pounds, reduced to 20 pounds at ends, and the remaining strakes of shell 22½ pounds.

The inner bottom plating is 12½ pounds. The distribution of inner bottom plating presents no special features, extending in this

type of ship to the watertight longitudinal on either side (No. 4), the watertightness being continued thence to protective deck by vertical bulkheads, and the coal is stowed against the shell, and three skins between the water and boiler rooms, obtained by the shell plating, the outer coal-bunker bulkhead, and the inner coal-bunker bulkhead.

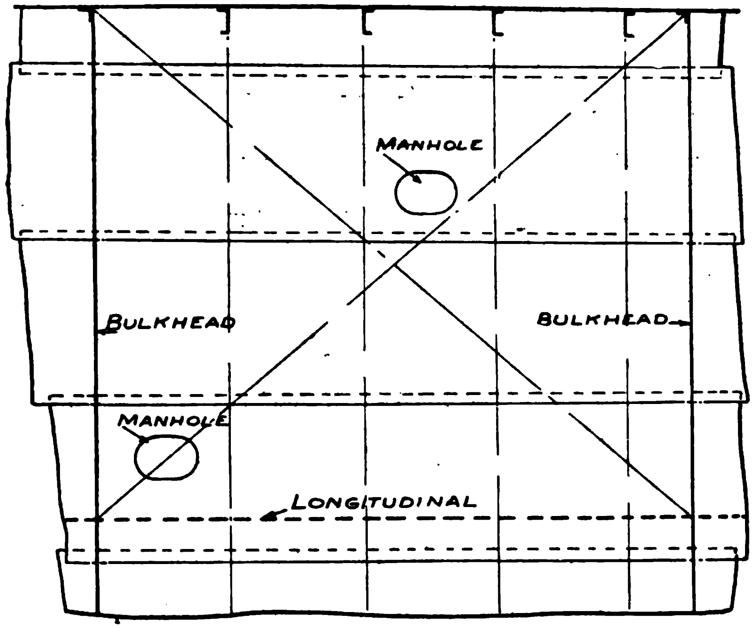
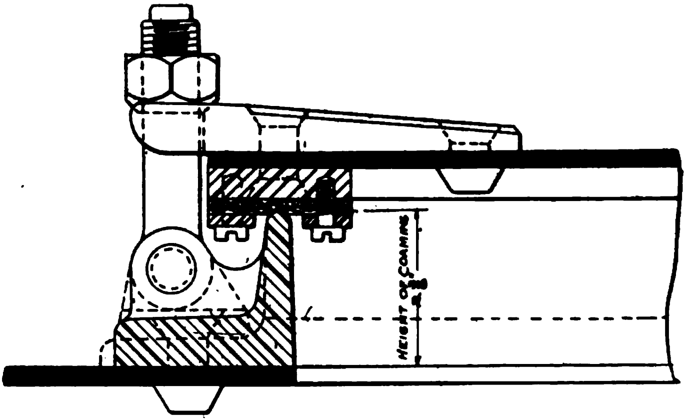


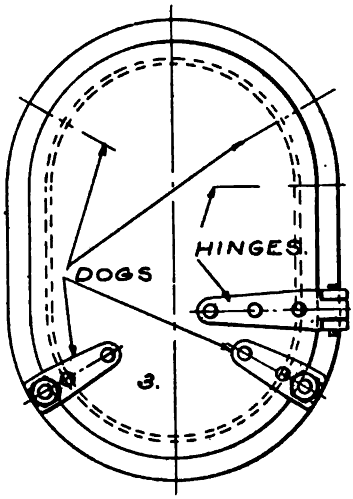
FIG. 128.—PLAN SHOWING EXTENT AND ARRANGEMENT OF MANHOLES IN AN INNER BOTTOM COMPARTMENT.

A sketch cross-section and a plan in outline showing watertight subdivision are indicated in Fig. 131, the sketch being for a modern armored cruiser.

Plating of a scout (420′ × 46′ 8″ × 3750 tons).—In general, this plating is 15 pounds, reduced to 12 pounds at ends. Inner flat keel plate is 17½ pounds, and the outer plate is 20 pounds. Inner bottom plating is 10 pounds, except center strake, which is 15 pounds, and 33 inches wide.

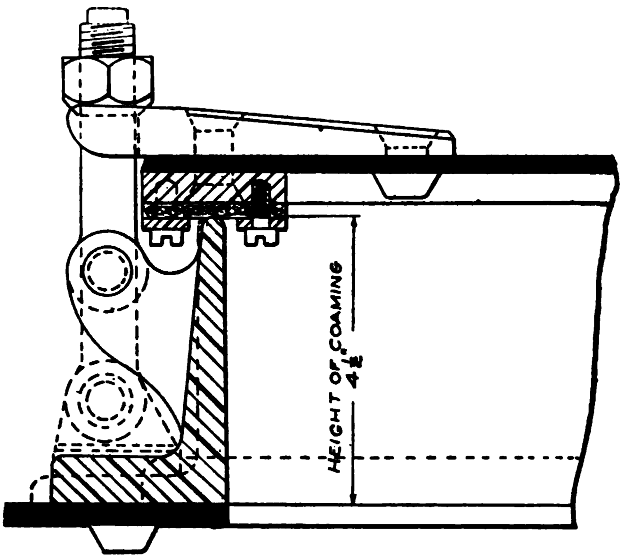


1. Edge of Low Coaming Manhole, Showing Type of Dog and Gasket.



Diagrammatic Plan View of Manhole, Showing Location of Dogs and Hinges.

FIG



. 2. Edge of High Coaming Manhole.

Plating of a cruiser of the Denver type (292′ × 44′ × 3200 tons).—The outer bottom plating is 15 pounds, including inner flat keel, the outer flat keel being 20 pounds, and the sheer strake doubled, of 15 pounds, with double-riveted straps at butts of each thickness. The *Denver* is a sheathed cruiser, being covered with planking in a manner which will be described later. The inner bottom is carried out to a margin plate or longitudinal just below the turn of bilge, the top of the inner bottom being kept level and the construction resembling somewhat that in the merchant service. The weight of inner bottom plating is 12½ pounds near middle of length, and 10 pounds at ends (Fig. 132).

FIG. 130.—SECTION THROUGH PORTABLE PLATE.

Outer and inner bottom plating of Dubuque class.—These ships, being composite, have no continuous outer bottom plating; it is worked under tanks, shaft alleys, longitudinals, shaft tube castings, struts, etc. There is a flat keel, in one thickness, of 20 pounds, reduced to 14 pounds at ends and garboard strakes in wake of magazines and inner bottom (which is under boiler room only) of 10-pound plate. The garboard strake is connected to the flat keel by single-riveted laps. Above berth deck, the plating is 14 pounds for about four-fifths of length, and forward and aft is reduced to 12 pounds, except sheer strake, which is 14 pounds throughout.

Plating of destroyer (300′ × 30′ 6″ × 1050 tons).—For this type of vessel, hard steel is used for deck stringers and sheer strakes, and for flat keel plates, garboards, and practically all shell plating; in some cases all shell plating. There is no inner bottom. The flat keel is 20 pounds, in one thickness, reduced at ends to 12½ and 10 pounds. Sheer strake is 20 pounds, reduced to 8 pounds at ends. All plating below the water-line is galvanized. Shell plating, in general, is 10 pounds, reduced to 7 pounds at forward end and 8 pounds at after

end, except garboard, which is 20 pounds, reduced to 12½ pounds aft and 7 pounds forward.

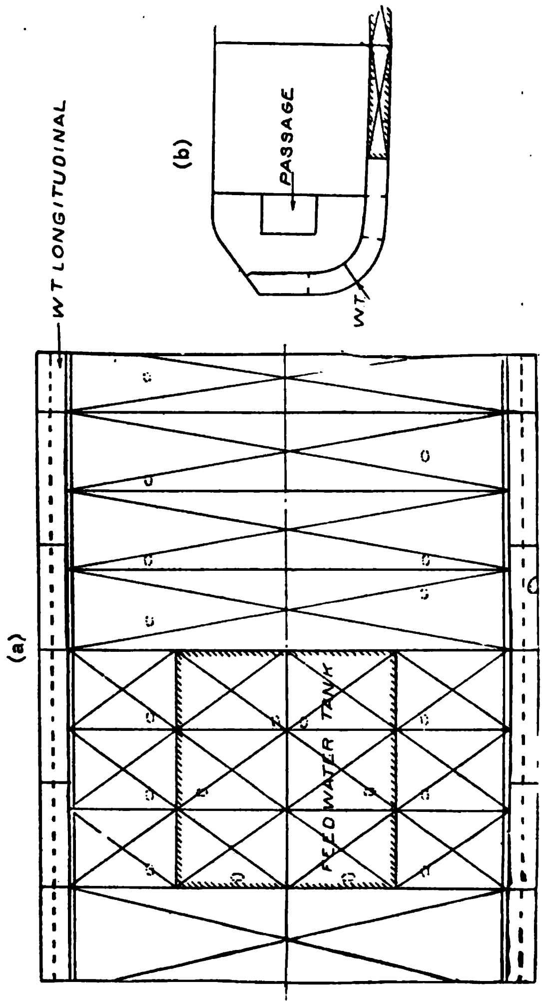


FIG. 131.—DIAGRAM SHOWING WATERTIGHT SUBDIVISIONS IN DOUBLE BOTTOM SPACE.
(a) Plan. (b) Transverse Section.

The thicknesses here given are for the same destroyer as in the previous chapter, being one of the latest and largest boats in the service.

17

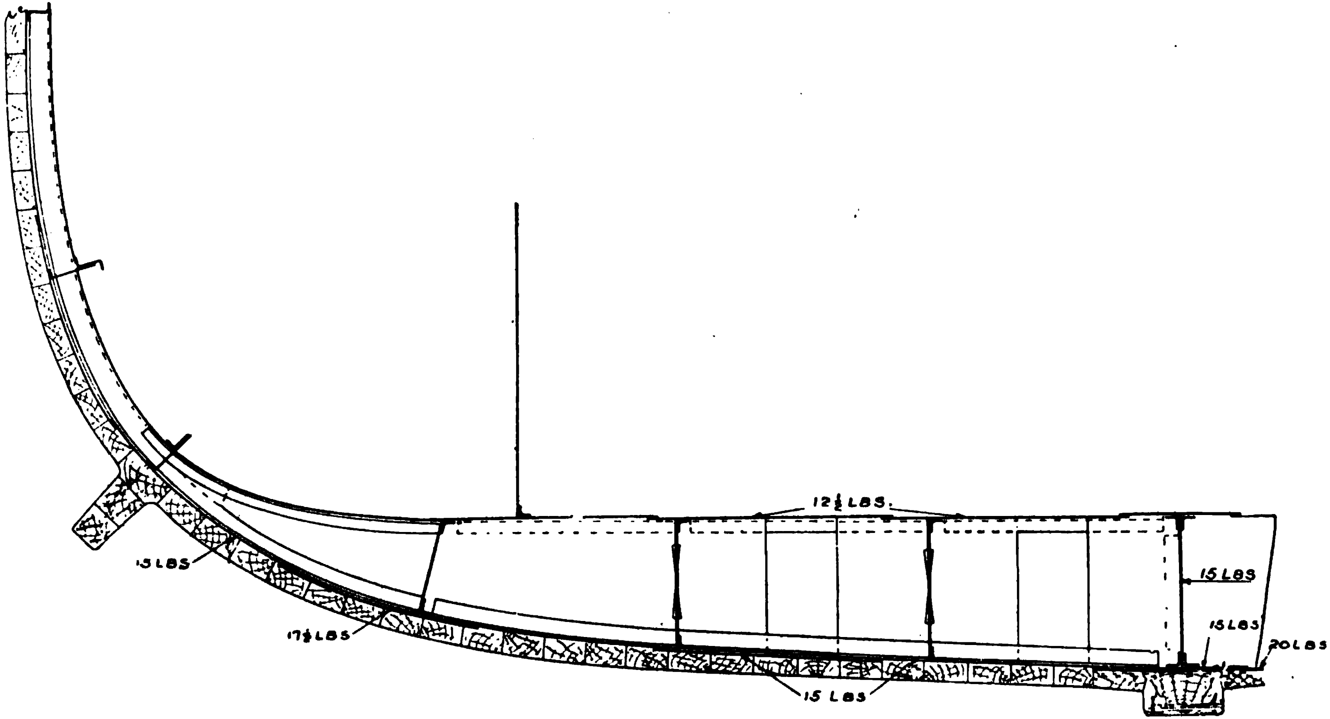


Fig. 132.—Section of U. S. S. Denver.

CHAPTER XVI.

WATERTIGHT SUBDIVISION, BULKHEADS, DOORS, ETC.

Rules for Numbering Compartments of Vessels of the United States Navy.

There are two systems of numbering compartments in use in the U. S. Navy. One obtained up to 1912, when the increasing size of ships and the large number of compartments made a change essential. As this system still obtains on the older ships both are given.

See Fig. 133.

Old System Prior to 1912.

A, *B*, *C*, *D*—Four principal divisions of ship.

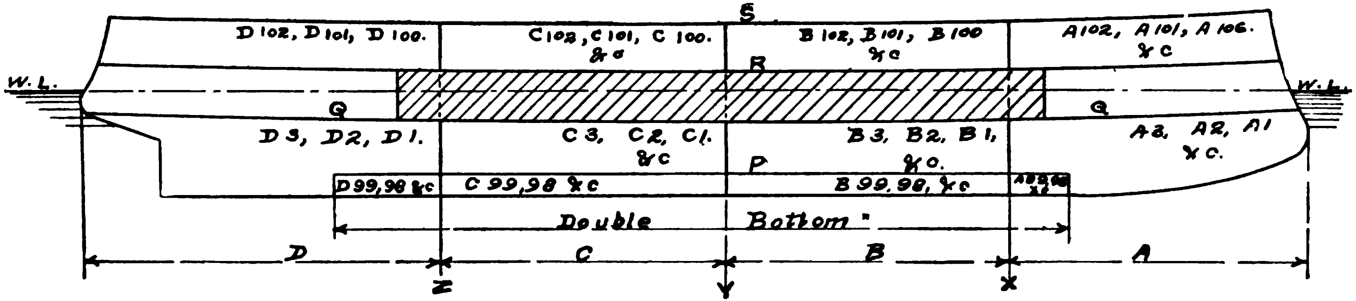
X—Forward transverse bulkhead of forward boiler compartment.
Y—After transverse bulkhead of after boiler compartment.
Z—After transverse bulkhead of after engine compartment.
P—Inner bottom.
Q—Protective, armored, or watertight deck.
R—Deck at top of armor belt.
S—Spar or main deck.

Division *A* is from stem to *X* " *B* " " *X* " *Y* " *C* " " *Y* " *Z* " *D* " " *Z* " stern.	Extending from keel to spar or main deck in the line of the bulkheads *X*, *Y*, *Z*, or these bulkheads prolonged when the bulkheads do not extend to the spar or main deck, the spaces between decks that extend through two of the principal divisions will be numbered as if situated in the forward division, and will have that number only.

1. Compartments above the armored, protective, or watertight deck to be numbered, beginning with 100 and upwards.

2. Compartments above the inner bottom, but below the armored, protective, or watertight deck, to be numbered, beginning with 1 and upwards.

3. Compartments in the inner bottom to be numbered, beginning with 99 and numbering downwards, commencing aft.



S
D 102, D 101, D 100.
C 102, C 101, C 100.
&c
B 102, B 101, B 100
&c
A 102, A 101, A 106.
&c
R
W. L.
W. L.
Q
Q
D 3, D 2, D 1.
C 3, C 2, C 1.
&c
B 3, B 2, B 1,
&c.
A 3, A 2, A 1
&c.
P
D 99, 98 &c
C 99, 98 &c
B 99, 98, &c
Double Bottom"
D
C
B
A
Z
Y
X

FIG. 133.

4. Compartments in each division to be numbered consecutively from forward to aft, except in inner bottom, which is the reverse.

5. Compartments on starboard side to have odd numbers; those on port side to have even numbers.

6. Magazines, shell rooms, etc., where explosives are stored to have the letter *M* after the number of the compartment, as *A. 5-M.*

7. The number of the compartment will always be prefixed with the letter indicating the principal division of the ship in which the compartment is located, as *A. 100, B. 3, C. 99,* etc.

8. If there are two fire rooms, the forward one must be marked *B. 1,* and the after one *B. 2;* should they be abreast each other, the one on the starboard side must be marked *B. 1,* and that on the port side *B. 2.*

9. If more than two fire rooms, they will be numbered in similar manner. The same arrangement applies to the engine rooms also.

Numbers *100,* or above, indicate compartments above the armored, protective, or watertight decks.

Numbers *99,* and under, indicate compartments in the inner bottom.

Numbers *1,* or above, indicate compartments above the inner bottom and below the armored, protective, or watertight deck.

After numbering all the compartments immediately above the inner bottom, those above the platform deck will be numbered in a similar manner, the numbers extending consecutively; the same applies to the decks above the protective or watertight deck.

New Method of Numbering Watertight Compartments.

(Approved by the Department in its indorsement of October 10, 1912, No. 8557-118.)

1. The ship shall be considered as divided into four principal divisions, lettered A, B, C, and D, from forward aft.

Division A.—This shall comprise all the space between the stem of the ship and the forward transverse bulkhead of the forward boiler compartment.

Division B.—This shall comprise all the space between the forward transverse bulkhead of the forward boiler compartment and the after transverse bulkhead of the after boiler compartment, or where

boiler compartments are located forward and aft of engine rooms, it shall comprise all the space between the forward and after transverse bulkheads of the forward group of boiler compartments and between the forward and after transverse bulkheads of the after group of boiler compartments.

Division C.—This shall comprise all the space between the after transverse bulkhead of the after boiler compartment and the after transverse bulkhead of the after compartment assigned to main propelling machinery or auxiliaries of main propelling machinery, or where boiler compartments are located forward and aft of the engine rooms, division "C" shall comprise all the space between.

Division D.—This shall comprise all the space between the after transverse bulkhead of the "C" (or "B") division and the stern of the ship.

2 These divisions shall be considered as extending from the keel to the highest deck in the line of the bulkheads, or the bulkhead prolonged. In case the bulkheads do not extend to the highest deck any spaces between decks that extend through two of the principal divisions shall be numbered as described in the case of a compartment situated entirely in the forward division of the two in which it is placed, and shall have this number alone.

3. All numbers in each division shall begin at the forward end of that division. The forward compartment of the double bottom in each division shall be *A-1, B-1, C-1,* or *D-1,* according to its respective division. The space next above the inner bottom, and the hold compartments where there is no inner bottom, shall be, starting from forward as above, *A-101, B-101, C-101,* or *D-101,* according to its division. Each successive level shall have a new series of numbers always beginning with the next hundred. The greatest number of levels (*i. e.,* decks, platforms, etc.), existing anywhere in the ship shall determine the highest series of hundreds to be used. By this method, all compartments on a given level will have numbers in the same hundreds series. Where a platform or deck steps down less than a deck height, no change in the hundreds series shall be made on account thereof.

4. The numbering of the compartments shall be prefixed always with the letter indicating the general division of the ship in which

it is placed, as *A-21, B-3,* etc. All magazines, projectile rooms, ammunition rooms, torpedo warhead room, etc., containing explosives of any kind shall have the letter *M* after the number of the compartment.

5. Compartments on the starboard side of the ship shall have odd numbers; those on the port side, even numbers.

6. The following sketches, Fig. 134, illustrate the general distribution of the numbers and divisions:

Valves and Watertight Doors.

1. Sluice and manifold valves of the drainage system are numbered and marked with the number of the compartments they drain and connect. All valves are marked with an arrow showing direction for turning handle to open them, and an index to show whether they are open or closed.

2. Watertight doors are numbered consecutively from forward to aft, with numbers distinctly marked on them.

For each U. S. naval vessel now built there is prepared for the guidance of officers and others on board a booklet called, "Booklet of General Information." This booklet contains the following, which, in conjunction with the booklet of small plans and a booklet of electrical auxiliaries furnished the ship, permit any one to easily become familiar with his ship:

(a) Introduction.

(b) Frontispiece (photograph of completed ship if obtainable).

(c) Table of contents.

(d) List of diagrams, sketches, plans, etc., included in this booklet.

(e) Data for battle conditions.

(f) List of finished plans and booklets supplied the vessel.

(g) Lists of fittings and auxiliaries duplicated on other vessels.

(h) List of compartments giving numbers, names, extent and location, and cubic capacities.

(i) List of coal bunker compartments, giving the summaries obtained from Coal Bunker Capacity booklets; also location and method of reading coal bunker gages, with sketch where necessary.

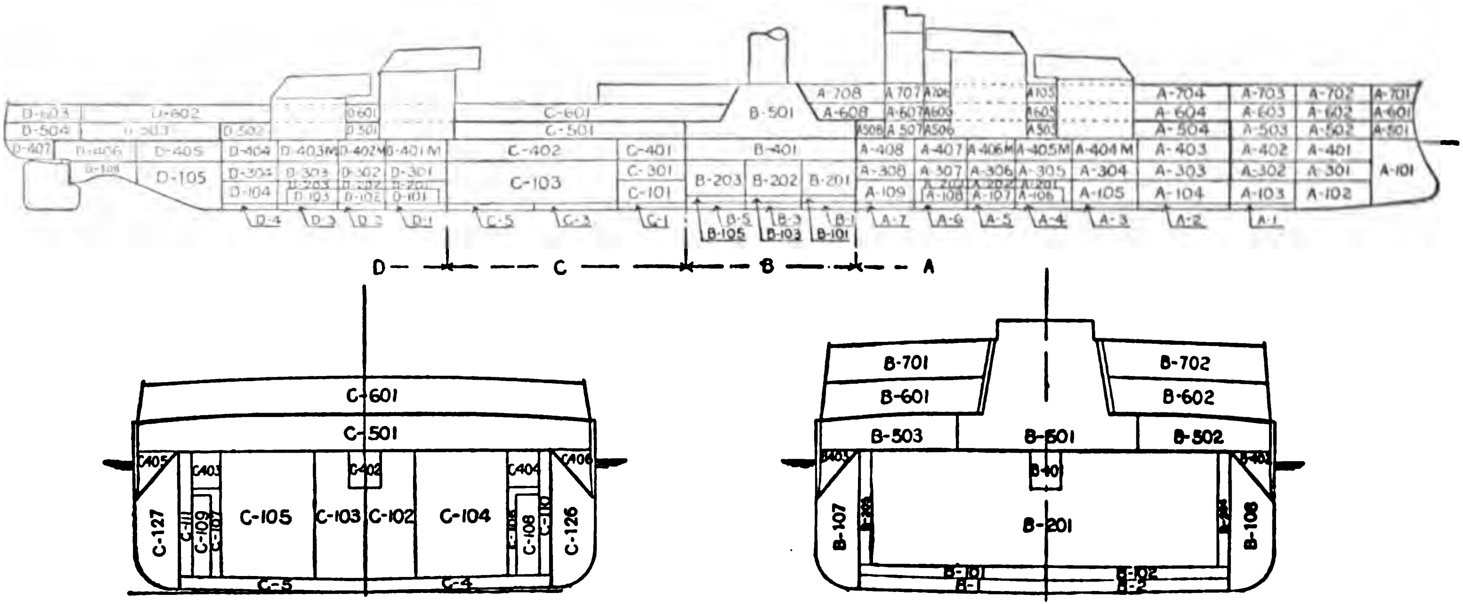


FIG. 134.—ILLUSTRATING NEW METHOD OF COMPARTMENT NUMBERING.

(j) List of oil-fuel compartments and capacities.

(k) Lists of doors, hatches, scuttles, manholes, etc., the compartments they connect, where operated from, and statement of those power-operated.

(l) Lists giving the number and location of all valves, plugs, etc., and their functions; record of marks and record of draft figures.

(m) Description of and directions for operating the following systems:

Drainage and flooding.
Fire main, flushing, and fresh water.
Ventilation.
Magazine cooling.
Gas ejecting.
Compressed air systems.
Fuel oil.
CO_2 fire extinguishing.

(n) Description and tabulation of voice tubes, showing points connected, size of tubes, and type of mouthpieces and headpieces.

(o) Descriptions of the following auxiliaries and arrangements and directions for operating (except electrical auxiliaries, which are in a separate book):

Steering gear.
Windlass.
Winches.
Capstans.
Coaling arrangement.
Ammunition handling and loading arrangements, showing guns supplied, rate of supply, chain of ammunition, and where ammunition is loaded and delivered.

(p) Test data of all important auxiliaries (other than electric) and systems and method of conducting tests.

(q) Method of replenishing flasks for fire-extinguishing system.

(r) List of compartments under compressed-air system for expelling water and list of compartments to be utilized as air locks for this system; also means and location of access to such compartments; and steps to be taken to make compartments airtight.

(s) On colliers, destroyers and other vessels carrying oil fuel or oil in bulk, the limit to which oil can be stowed should be indicated.

(t) Diagrammatic plans of arrangements listed below reduced by photographing. The information given on these plans shall be limited to that necessary for the purpose for which intended:

Drainage in hold and magazine sprinkling, second platform.

Magazine sprinkling and fire main, first platform, and location of deck plates.

Fire main second deck and profile.

Flushing system, main, second and third decks.

Fresh water system, main, second and third decks.

These plans should indicate the following:

Leads of all pipes except connections to plumbing fixtures in rooms.

Valves and type of same.

Lead of pipes up or down through decks.

Numbers in compartments through which pipes pass.

Bulkhead numbers.

Doors.

Pump connections to flushing and fresh-water systems.

The information inserted in Section e, Data for Battle Conditions, shall be the answers to the various items or questions noted below, which answers shall be prepared in the office of the superintending constructor and submitted to the bureau for approval before inserting in this booklet.

The plans, diagrams, or charts considered necessary or advisable for showing the information desired shall be prepared and incorporated in this section in manner similar to the diagrammatic plans referred to under item (t).

ITEMS OR QUESTIONS.

Most desirable draft and trim at which to enter an action.

Best means to obtain this condition if the mean draft is less than the most desirable mean draft.

From what bunkers or tanks it is desirable first to use fuel if the mean draft is greater than the most desirable mean draft?

What hatches and doors are by the design supposed to be left open during an engagement?

What hatches and doors should be kept closed throughout an engagement?

Passages and routes of escape from the most important spaces during an action.

What suctions to blowers should be kept open during action, and what necessary steps are to be taken for closing them in case smoke begins to be drawn below decks?

What action should be taken in regard to the various ventilation systems in going into action?

What special preparations in connection with the drainage system are necessary before going into action?

What is the best method of righting a list or change in trim in case certain of the large compartments are flooded?

What are the routes of escape from the more important large compartments in case they are flooded?

What special instructions in regard to the fire-extinguishing system (CO_2) should be taken upon going into action?

What special instructions should be carried out in regard to making ready for service the compressed-air system for expelling water?

Data regarding damaged stability in accordance with bureau's previous instructions. (This shall also appear in the inclining experiment booklet as heretofore.)

Subdivision.—The main methods of obtaining watertight subdivision in a warship are:

(1) Watertight inner bottom with watertight longitudinals and floors.

(2) Watertight decks and flats.

(3) Transverse bulkheads, watertight.

(4) Longitudinal bulkheads, watertight.

(1) and (2) have been dealt with, and we have seen that in certain types of ships the valuable feature of an inner bottom has to be dispensed with, owing to the cost in weight and space. In all warships, however, at least three of the four means above are used.

This chapter is to deal generally with bulkheads, which, in addition to dividing the ship into watertight compartments, form a considerable part of the ship's structural strength.

Transverse bulkheads.—Figs. 135 and 135a show in outline the number and location of such bulkheads in the types of ships which

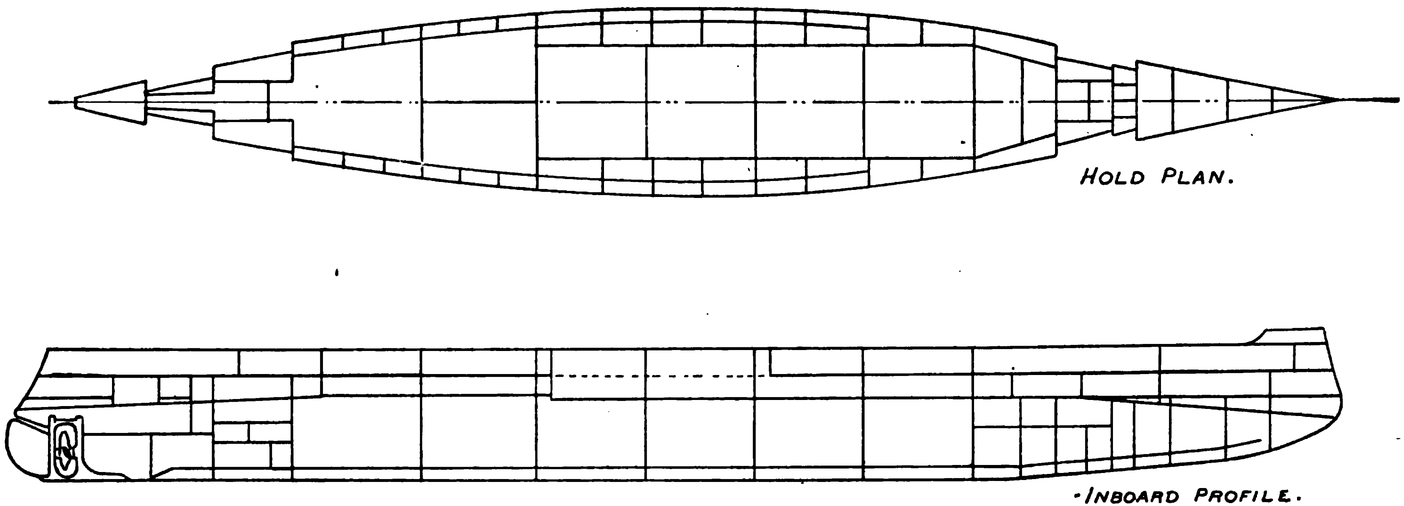


FIG. 135.—" COLUMBIA."
Diagrammatic Location of Bulkheads and Decks.

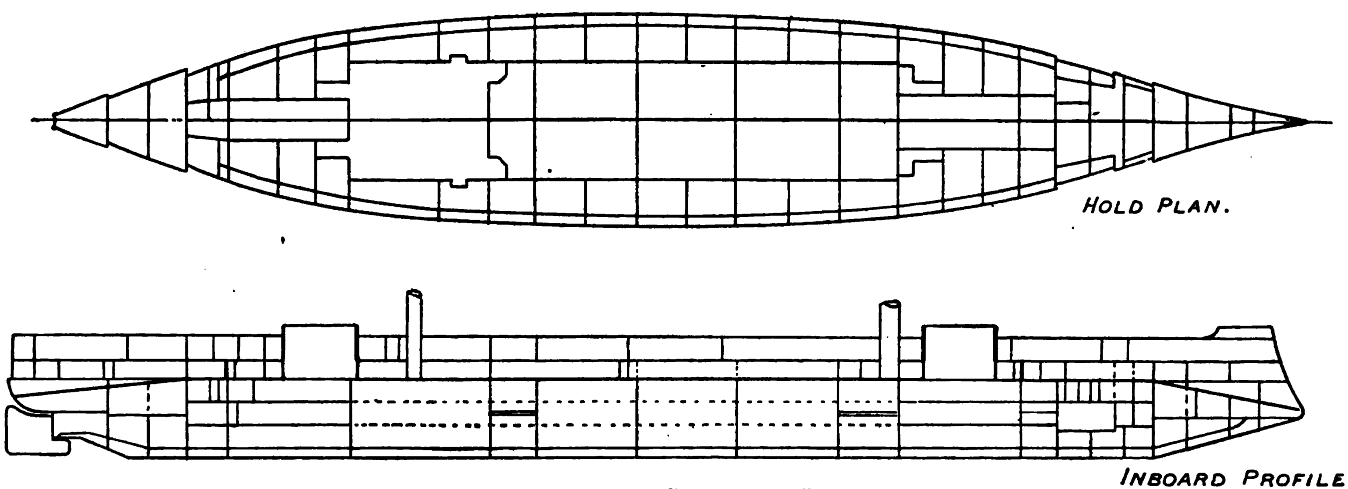


FIG. 135a.—"CONNECTICUT."
Diagrammatic Location of Bulkheads and Decks.

they represent. The bulkhead nearest the stem, and extending to berth deck, is the *collision* bulkhead. Instances are not wanting, in merchant ships, where, after collision, this bulkhead has remained intact and saved the ship. No openings are fitted in it.

The type of construction of any bulkhead is determined by the area and depth of unsupported plating likely to be exposed to water pressure. All bulkheads in U. S. ships are tested during building to the water pressure which they are apt to be called upon to withstand in service, by actually filling the compartment which they bound, to the required height. Main longitudinal bulkheads, such as centerline bulkheads, when fitted, and coal-bunker bulkheads, are continuous, the transverse bulkheads being intercostal between them, but, except in particular cases, the transverse and longitudinal bulkheads are both continuous from inner bottom to protective deck. Forward and abaft the machinery spaces, the transverse bulkheads are well supported by decks and flats and the stiffening required by them is relatively small. Such bulkheads, except where they form supports for turret structures and require special stiffening in order to act as struts, are usually formed of a lower strake next the inner bottom, of 13 pounds, next strake 11 pounds, and remaining strakes 9 pounds, strakes being worked horizontally clinker fashion, except where double stiffeners are worked, and then on the raised and sunken system. The stiffeners are of channels $6'' \times 3\frac{1}{2}'' \times 3\frac{1}{2}''$, spaced 3 feet, bracketed at heads and heels by flanged brackets $24'' \times 18''$ of 15-pound plates. (Fig. 136.)

Turret support bulkheads are built of 15-pound plating, with stiffeners and brackets as described above, and such extra stiffening as is required to suit their special purposes.

The transverse bulkheads separating engine and boiler rooms, and the other main transverse bulkheads, consist of the two lower strakes of 14 pounds, next strake 12 pounds, and remaining strakes 10 pounds. The stiffeners are of $6'' \times 3\frac{1}{2}'' \times 3\frac{1}{2}''$ channels, with 15-pound bracket 36 inches deep at bottom and 15-pound brackets 30 inches deep at top. The stiffener is reinforced on inner edge by $3'' \times 3''$ angle and a 20-pound face plate. Stiffeners are spaced 4 feet, and worked on both sides of bulkhead where bulkhead has no support from flats; elsewhere on one side only.

Transverse bulkheads in way of inner bottom are bounded thereby, and the watertightness is continued to outer bottom by watertight frames.

Intermediate between main transverse bulkheads, transverse divisional bulkheads are fitted in bunkers, as shown on hold plans in Figs. 134 and 135.

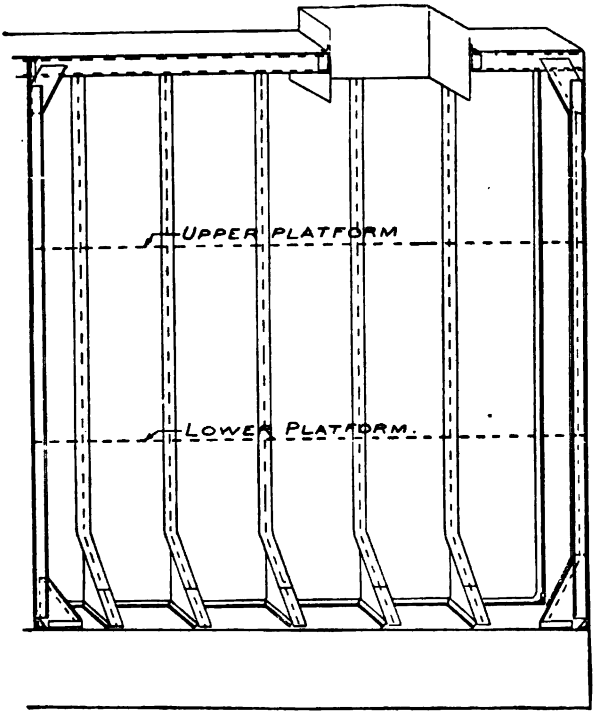


FIG. 136.—BULKHEAD STIFFENERS.

Types of bulkheads and their relative location and construction are shown in models on view in the model room.

Fore and aft longitudinals, vertical keel, etc., are worked continuous through all transverse bulkheads, watertightness being secured where the type of longitudinal is that forward and abaft inner bottom, with collars. (Figs. 137 and 138.)

A number of transverse bulkheads are carried watertight up to

second deck, which is an important point in view of sinkage, heel and change of trim that might ensue after damage.

All the watertight bulkheads are bounded at top by a watertight flat or carried well above water, to insure, as far as possible, confining water which may enter on one side of them.

Longitudinal bulkheads.—There are a number of small longitudinal bulkheads forming boundaries of magazines; these assist in maintaining watertight subdivision, but, as they are of small area, are of 10-pound plate, stiffened by 4″ × 3″ angles, spaced 2 feet, with angle clips at top and bottom.

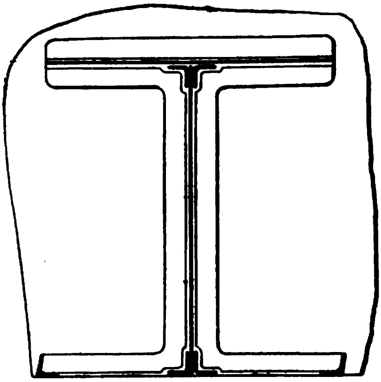


FIG. 137.
VERTICAL KEEL STAPLING.

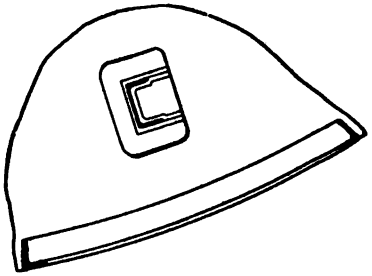


FIG. 138.
STAPLING AROUND A LONGITUDINAL PASSING THROUGH A FLOOR.

The principal fore and aft bulkheads in a large ship are:

(1) Centerline bulkhead in engine room, and, in U. S. ships up to *Michigan* class, in boiler room.

(2) Inner coal-bunker bulkhead.

(3) Outer coal-bunker or wing bulkhead.

(4) Upper coal-bunker bulkhead.

All these except (4) are shown in Figs. 135 and 135a; (4) is generally nearly above (2) and between protective and second decks.

Centerline bulkhead.—This bulkhead extends, in most of our earlier battleships, from the after end of engine room to the forward end of boiler room. In designs subsequent to the *New Hampshire* it is omitted in boiler rooms. It is watertight from inner bot-

tom to protective deck. Provision must be made to prevent water running over the top in case one engine room is flooded, by carrying this bulkhead up to the second deck if necessary, or by fitting watertight hatches in the protective deck. It is essential that this bulkhead be amply strong; it is of 14 pounds for the two lower strakes, 12 pounds next, remainder of 10 pounds. Stiffeners spaced 4 feet, of $6'' \times 3\frac{1}{2}'' \times 3\frac{1}{2}''$ channels on each side, reinforced on inner edge by $3'' \times 3''$ angle and 20-pound face plate, in manner similar to main transverse bulkheads. Plating is on raised and sunken system, with parallel liners. Butts of plates are lapped and double-riveted.

Inner coal-bunker bulkhead.—This being supported by divisional bulkheads in coal bunkers is plated as above, except that it is built on the clinker system, with double-riveted laps and butts, and stiffeners on one side, of type as specified for centerline bulkhead above.

Outer coal-bunker or wing bulkhead.—This bulkhead, when fitted, sometimes forms a vertical continuation of the inner bottom, is plated the same as the inner coal-bunker bulkhead, and generally stiffened in the same way as the inner bulkhead.

In some of the latest ships this bulkhead has special treatment steel plating to furnish protection against underwater damage. When so fitted no openings are fitted in this bulkhead and the stiffening used is of special strength.

Upper coal-bunker bulkhead.—This being only worked from protective to gun deck, will not be called upon to stand much pressure; it is of 10-pound plate, stiffened by $4'' \times 3''$ angles spaced 2 feet. Other structural bulkheads above protective deck are built in this way.

The beams of a ship run continuously through longitudinal bulkheads, and in order to make the upper part of such bulkheads watertight, angle bars are smithed to fit the space between beams. The riveting is close-spaced and the staples carefully calked. (Fig. 139.)

Bulkheads under barbettes and turret foundations are specially stiffened with additional $6'' \times 3\frac{1}{2}'' \times 3\frac{1}{2}''$ channels, as necessary, to assist in supporting the weight and shock of gun fire.

Above second deck, the bulkheads are only made watertight to 12 inches above deck.

Numbering of bulkheads.—Transverse bulkheads are distinguished by the number of the frame on which they are located. Longitudinal bulkheads are distinguished by name and also by numbers of frames between which they extend, as *centerline bulkhead, inner longitudinal coal-bunker bulkhead, bulkhead 68 to 79, etc.*

Water testing.—All watertight decks, flats, and bulkheads, and the outer bottom, inner bottom, and watertight floors are tested for watertightness under pressure. The following quotation as to watertight testing is made from the general specifications for building ships of U. S. Navy, as indicating the requirements enforced as to the structure, in addition to which are specific requirements as to tests of piping, etc.

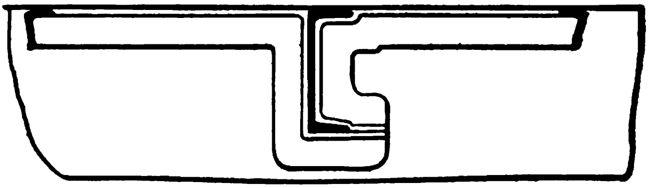


FIG. 139.—BEAM STAPLING.
Longitudinal Elevation.

Watertight compartments.—The following compartments shall be tested by filling them with water under the test head for main structural bulkheads specified in the detail specifications:

All compartments adjacent to the outside plating and below the deck next above the speed trial water-line, except engine and boiler rooms.

One of the engine rooms, one of the boiler rooms, and typical interior compartments below the deck next above the speed trial water-line; these compartments shall be selected by the superintending constructor subject to the approval of the bureau.

All compartments intended to be used for the storage of fuel oil or fresh water (potable or reserve feed).

All trimming tanks.

Care shall be taken in making these tests that the doors in such bulkheads as are designated as main structural bulkheads are left

open or other means provided to relieve these partition bulkheads of the heavy test pressure on adjacent bulkheads.

In the case of bulkheads below the deck next above the speed trial water-line not designated as main structural bulkheads, the superintending constructor will select one or more compartments bounded either wholly or in part by such bulkheads, which compartments shall be tested by being filled with water under a head equal to 5 feet above the top of the bulkhead. Where this head would exceed the specified head for main structural bulkheads, the lesser head shall be used.

If any of the typical compartments selected as specified above fail to pass a satisfactory test, additional similar typical interior compartments, designated by the supterintending constructor, shall be tested.

The typical compartments referred to are to be understood as those bounded by bulkheads (one of each variety) which may be expected to be the least efficient in withstanding the test pressure, with particular reference to wide spacing of stiffeners, cut stiffeners, difficult conditions of bracketing, etc.

All other compartments below the deck next above the speed-trial water-line not tested in accordance with the foregoing shall be tested under a head of water equivalent to the height of that deck amidships.

Watertight members above the deck next above the speed-trial water-line, including gunport shutters and turret watersheds, doors, hatch covers, skylights, air ports, and turret and conning-tower bucklers, shall be tested by playing a hose on them or by such other means as may be considered necessary by the superintending constructor to be assured of satisfactory workmanship.

All cofferdams above the deck next above the speed-trial water-line shall be tested with water under a head of 2 feet above the top of the cofferdams.

Shaft tubes shall be tested to a pressure determined by the mean trial draft of the vessel as follows:

Draft less than 10 feet.................	15 pounds.
Draft 10 feet to 20 feet, inclusive.......	20 "
Draft over 20 feet.....................	30 "

Special watertight work not covered in the above shall be tested to the satisfaction of the superintending constructor.

Compartments when tested shall be structurally complete, and with permanent doors, manholes, and hatches fitted in place, unless specially authorized to the contrary by the bureau.

If the superintending constructor so requires, all permanent metal work and fittings in the compartment, attached to any of the boundaries thereof, shall be fitted, riveted, and calked complete in all respects. One manhole or one door in each compartment may however, be fitted with a testing plate, except for magazine and fuel oil compartments, for which all doors and manhole covers will be in place.

Not more than one coat of paint (priming coat) shall be on any part of the structure tested, and such paint shall be thoroughly dry. Any thick paint in the vicinity of watertight joint shall be scraped off if so required by the superintending constructor.

The water testing of compartments adjacent to the outside plating shall be done before launching.

No testing shall be done in freezing weather nor in weather when on account of excessive sweating of the metal the detection of the leaks would be difficult.

All compartments adjacent to that being tested shall be thoroughly dried and every facility afforded for inspection and detection of leaks.

When a compartment is ready for inspection the superintending constructor shall be notified, and water shall not be admitted until he or his representative shall have inspected the compartment and authorized proceeding with the test.

Bulkheads, decks, and flats subjected to a head must stand the pressure without serious permanent set, or deflection sufficient to cause serious leakage or to approach collapse, or open the calking edges.

Any leaks which develop by the test shall be corrected by and at the expense of the contractors, and where they occur and it is not practicable to properly correct them during the test, the compartment shall be refilled under the specified head and the testing continued until tightness is obtained.

The practice of injecting red-lead putty to stop leaks shall be limited to a minimum, and shall be subject to approval in each case by the superintending constructor, and no holes for such injection shall be drilled without his approval.

The trimming tanks, fresh-water tanks, fuel-oil tanks, feed-water tanks, and all cofferdams, shall be absolutely tight under the test pressure.

Special care shall be taken to secure absolute watertightness of all flats, and coamings bounding them, on which tiling is to be laid, and these shall be tested both by hose and by flooding to the height of the coaming, such test to be made before the tiling is laid and before any paint, cement or other coating is applied. All blocks for securing the fixtures in such places shall be in place when the test is made.

The same degree of watertightness shall be obtained for doors, hatches, etc., as for structural parts in the immediate vicinity, except that for doors fitted metal to metal a leakage of 2½ gallons per minute will be allowed.

The tests shall be so conducted that each type of watertight stuffing box and flange connection shall be thoroughly tested.

Air tests, using a solution of soap in water to search for leaks, may be substituted for the water tests for interior compartments, if the contractor so desire and subject to the specific approval of the bureau, except in the case of compartments which are to be subjected to the head specified for main structural bulkheads and compartments intended for the stowage of fuel oil.

A large number of holes are necessary in bulkheads for the purpose of connecting fittings to the bulkheads. It is important to note that the screws, etc., used for such attachments are watertight, and that if any are removed, the hole is suitably closed.

Glands and stuffing boxes are fitted for passage of all pipes, wire, etc., through watertight bulkheads, and should be examined periodically to see if in proper condition.

The detail requirements as to obtaining satisfactory watertightness of such joints and fastenings are contained in a pamphlet issued by Bureau Construction and Repair called " Instructions for making

joints and obtaining watertightness and oil tightness through bulkheads, decks, etc., on vessels of the U. S. Navy."

The large openings in watertight bulkheads necessary for access from compartment to compartment, are fitted with suitable watertight doors. These in the U. S. Service are of various sizes to suit the particular location for which desired. They are of three general types:

(1) Hinged watertight doors.
(2) Vertical sliding doors.
(3) Horizontal sliding doors.

Type (1) is always operated by hand. Types (2) and (3) are operated, (a) by hand only, (b) by hand and by power, which may be hydraulic, pneumatic, or, as in the latest type, electric.

Each of these types of doors differs in details in different classes of vessels owing to improvements and minor variations in practice of the building yards. Models showing these are in the model room.

Automatic ventilation valves.—As will be explained in the Chapter on Ventilation, the earlier types of ventilation systems required certain automatic valves at watertight bulkheads to preserve the watertightness. These are not now fitted, but the operation of those that have been fitted is referred to in the Chapter on Ventilation.

CHAPTER XVII.

STEMS, STERNPOSTS, RUDDERS, AND SHAFT STRUTS.

NOTE.—Models in the model room illustrate the subject-matter of this chapter, and should be consulted in connection with it.

Stems.—The simplest form of stem is made of a flat bar to which the plating at forward end of ship is secured. This form is generally used in the merchant service and in the smaller cruisers, gunboats, and destroyers in the U. S. Service. For larger warships it has been customary in the past to provide a heavier form of stem, securely backed up to form a ram, so that the vessel may ram another without suffering severe damage herself.

The present tendency is to depart from this form of stem, at least in its more exaggerated forms, as it complicates the handling of anchors, and seagoing officers at present doubt the practicability of ramming in action. The latest ships, while retaining somewhat of the ram form, have none of the massive structure intended for actual ramming.

The usual and most effective form of stem for ramming is one having a ram below water, projecting forward so that it shall damage the unarmored under-water portions of the structure of the enemy's ship and project well inside the enemy before being brought up by the stronger structure above.

Stems of this character in the U. S. Service are made of cast steel. It is customary, on account of the complicated form and great weight, to make these stem castings in two pieces, the two being connected together about the level of the third deck by a suitable scarf. This is sometimes made a table scarf, and at other times a side scarf. Fig. 140 shows the construction of such a stem. In the most recent ships the upper part is formed by a bent plate.

Assuming the ram to be fitted, it is essential to provide suitable support by the adjacent structure. The following provision is made for this:

(1) The outer bottom plating is doubled in thickness and rabbetted (*i. e.,* recessed) into the casting.

(2) The bow protection is rabbetted into the casting for part (sometimes all) its thickness. Dotted lines in Fig. 140 show rabbet lines.

(3) The protective deck is well connected to a large projection on inside of stem casting. See *A*, Fig. 140.

(4) A breast hook or horizontal ram plate of 2 to 3 inches is worked, well connected to horizontal web inside ram and extending well back. See *B*, Fig. 140.

(5) The vertical keel runs up to stem and is well connected to vertical web inside ram.

(6) In many ships, additional stiffening plates, called vertical side ram plates, are fitted.

From the above it is seen that great care is taken to suitably support the stem, both against the direct shock, and also, by (3) and (4), against the bending action brought into play when the ships swing after impact.

In the *Denver* class, to prevent corrosion from galvanic action between copper sheathing and steel, a bronze stem is fitted. Manganese bronze is employed for this purpose on account of its physical qualities.

Sternposts.—In the sheathed ships of the *Denver* class, the sternposts are of bronze, as are the stems.

The sternpost of a single-screw or triple-screw ship has to be formed to receive the propeller and also to form a support on which to hang the rudder.

Nearly all vessels of any size now in the U. S. Service have more than one screw, so that the function of the sternpost, in addition to receiving the after end of the plating, is to receive and carry the rudder.

The shapes of sterns of ships vary considerably in different classes, but in all warships a condition essential to the safety of the ship is to be fulfilled, *i. e.*, that the stern be so formed that rudder and steering gear will be well below water and under suitable protection. The stern is therefore carried well abaft the rudder-head to accomplish this purpose.

In U. S. battleships the sternpost is a casting, with projections on which the rudder can be supported. Fig. 141 shows a typical

sternpost for a recent battleship, and for our armored cruisers it is not essentially different.

It is customary to take the weight of the rudder at the top of the sternpost casting, which has to be made specially strong on this account. Intermediate or steadying pintles are provided below.

Rudders.—It should be noted that rudders of the more recent battleships and armored cruisers and large twin-screw ships are of the *balanced* type, while for the *Minneapolis, Denver,* and smaller ships they are of the *unbalanced* type. (See Fig. 142.)

Up to within recent years, rudders have been of nearly rectangular shape, hinged on the fore side, and unbalanced. Rudders of this type were fitted in our earlier steel cruisers and our earlier battleships. The weight in this type of rudder is taken at the head, as later explained in the case of balanced rudders. The sternpost projections, including the one at the bottom in which pintles are fitted, simply fix the points against bending and act as bearings in rotating.

The frame of the modern rudder, whether balanced or not, is cast steel, lightened out as much as possible, and in way of the turning axis necessarily of massive construction to stand the large twisting moment. The sides are covered with 15-pound plates, and the space inside filled with white pine.

The rudders of the more recent ships are all balanced, *i. e.,* a portion of the area is fitted forward of the axis, which renders the steering easier, as the center of pressure is brought nearer the axis.

If we test a rectangular plate by towing it through the water, inclined at an angle of 30° to 40° to line of advance, it is found that the center of pressure is about one-third the breadth from leading edge. Therefore, to balance a rudder, considerably less than half the total area should be before the axis. Generally from 12 per cent to 20 per cent of the total area.

With a balanced rudder the twisting moment is small, and less power is needed in the steering gear than with the unbalanced type.

The pressure per square foot of rudder area increases as *square of speed,* so that comparing 22 and 18 knots, the proportion of pressure for equal areas is $\frac{484}{324}=1.5$, *i. e.,* an increase of 50 per cent.

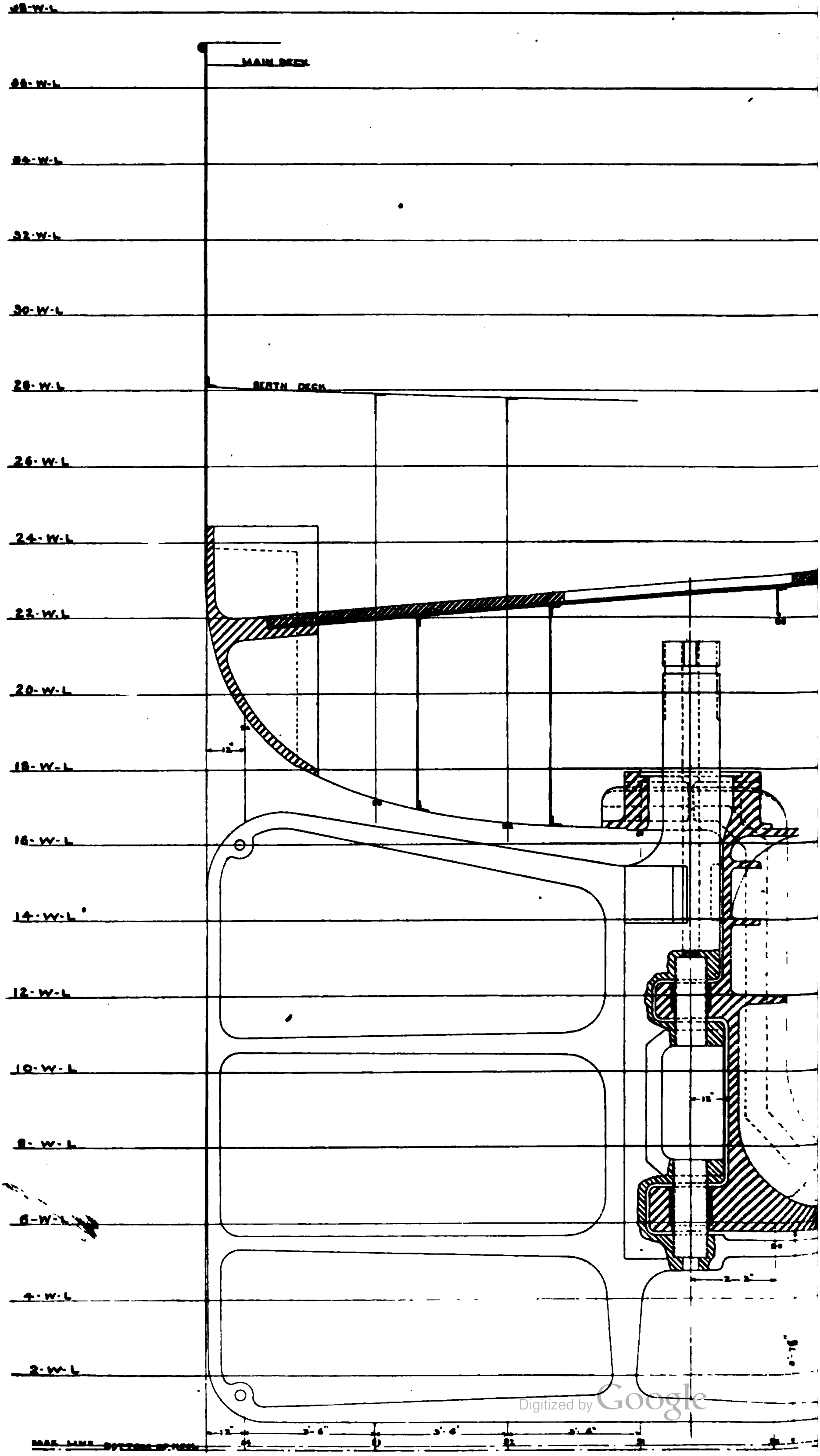
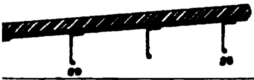
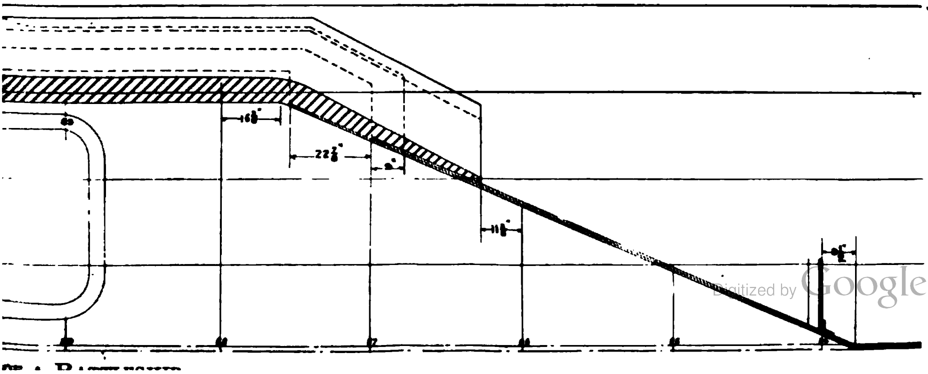


FIG. 141.—STERN





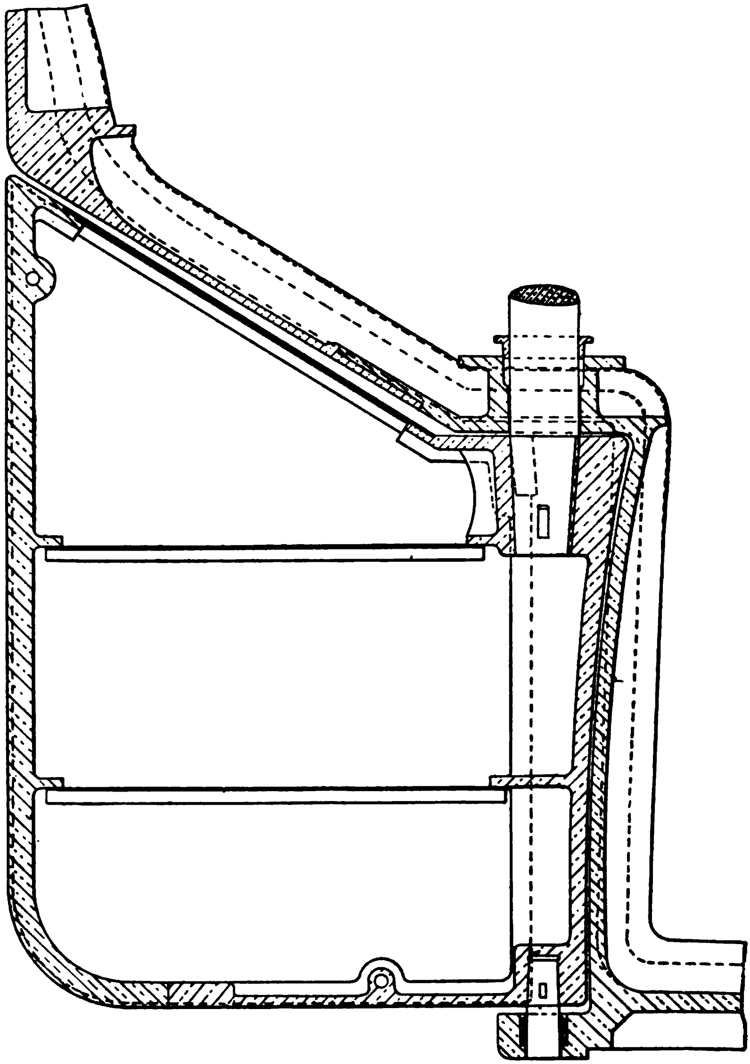


FIG. 142.—UNBALANCED RUDDER.

From this it would appear that in a ship of 22 knots, the steering gear would be much more massive than in a ship of 18 knots, and steering by hand would be practically impossible.

The weight of the rudder is taken at the top of rudder-stock by the sternpost.

From Fig. 143 it will be seen how the weight is taken. At the top of the sternpost a recess is formed, and in this is fitted a bearing ring, in halves, encircling the rudder-stock. The rudder crosshead is fitted on over the stock, and keyed for twisting by two rectangular keys at 180° from each other. The bottom of this crosshead slides on a circular metal bearing attached to the sternpost, and the weight of the rudder is taken by an annular key or ring, fitting into a recess at the upper end of the stock. Above this is fitted a circular piece of metal, also keyed to the rudder-stock, on which is fitted a band brake for locking the rudder when the steering gear is broken. Figs. 144 and 145 show further details of rudder, crosshead and steering gear arrangements of the right and left hand screw type of which a model may be seen in model room.

In destroyers and torpedo boats the rudder-stock generally projects up through the main deck and is fitted with a quadrant to which the steering ropes attach. These ropes lead forward and wind on a drum operated by the steering engine, located generally in or below the conning tower.

For high speeds, with balanced rudders fitted, the *bending* or tendency to bend is of importance as well as the *twisting*. This is indicated by sketch (Fig. 146), the rudder being held at one end and supported at the pintles. It is evident that in either case a considerable force has to be taken by the lower pintle, and a large bending moment at the rudder head. In designing, the condition going astern should be investigated, as this may be the worst case.

The twisting moment combined with the bending moment will determine the necessary size of rudder-stock.

In any warship rudder, as the head is under water, the hole in the stern has to be made watertight. The construction of this work, its stuffing-box and gland, is shown in Fig. 143.

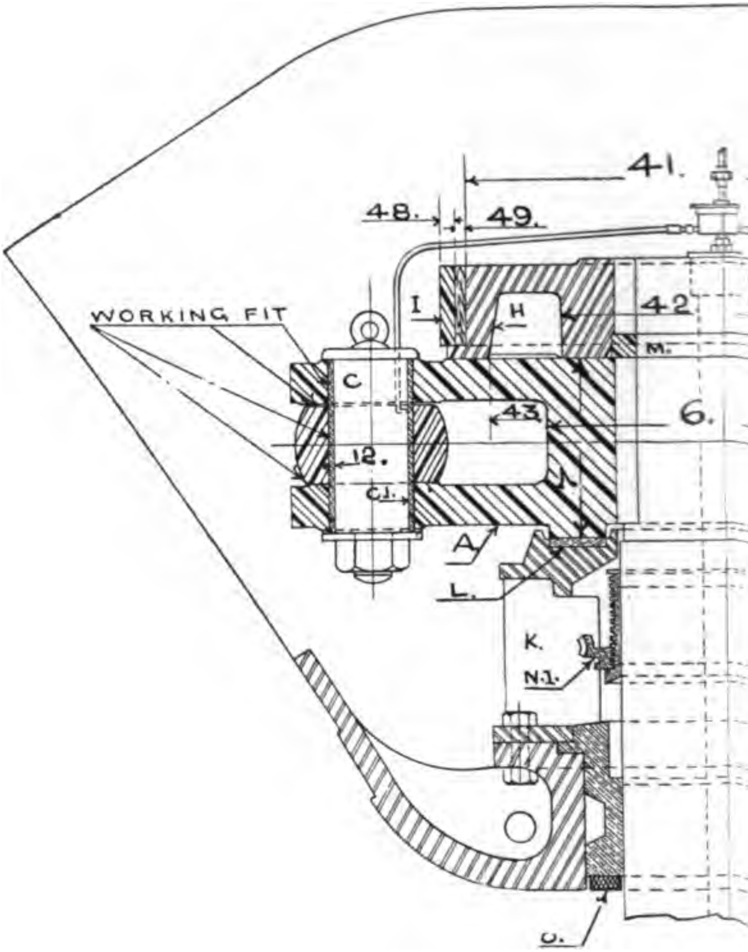
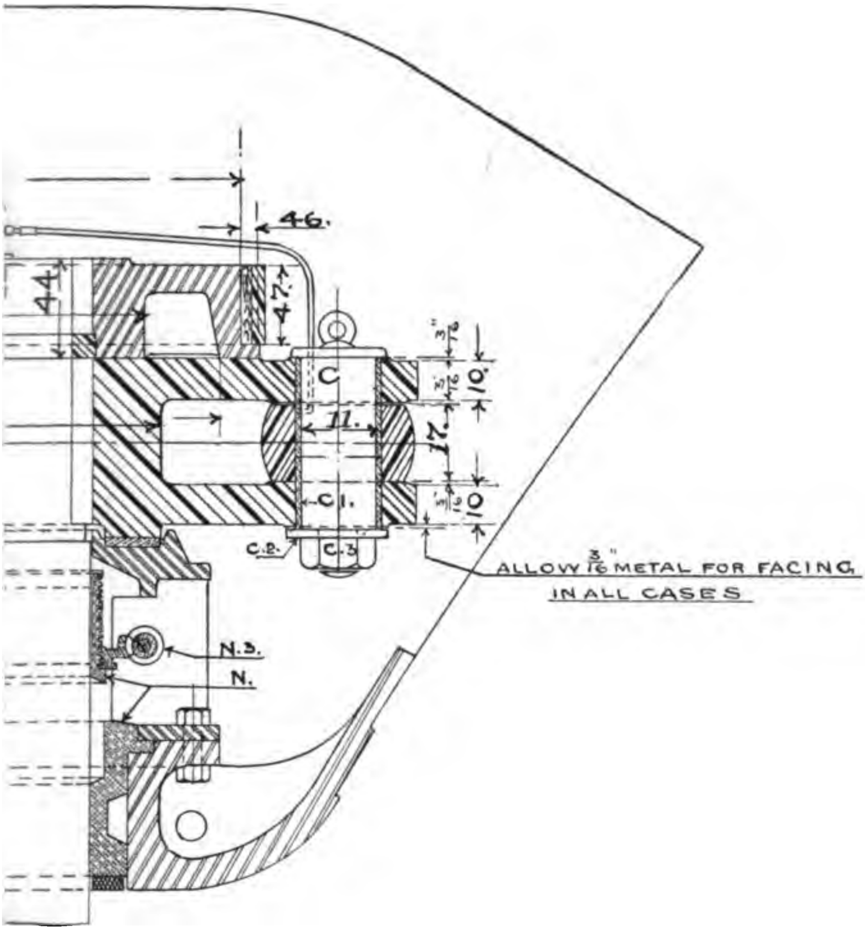


FIG. 143.—SECTION THROUGH FITT



= 1 Ft.

NGS AT HEAD OF RUDDER STOCK.

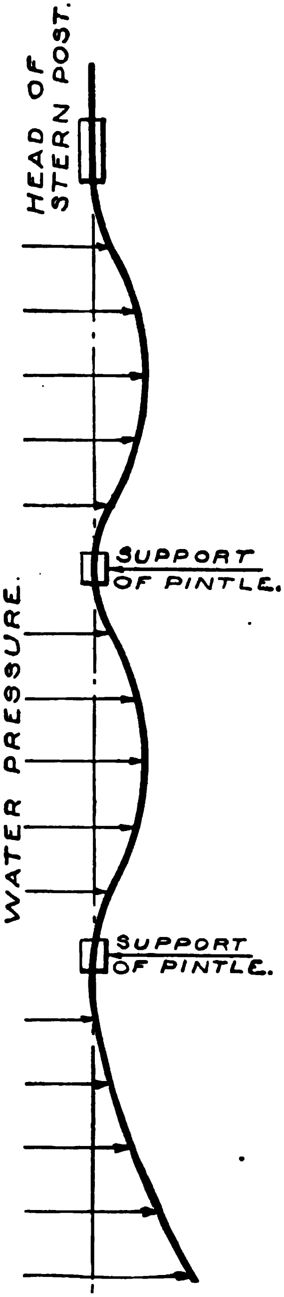


FIG. 146.—DIAGRAM SHOWING TENDENCY OF RUDDER STOCK TO BEND.

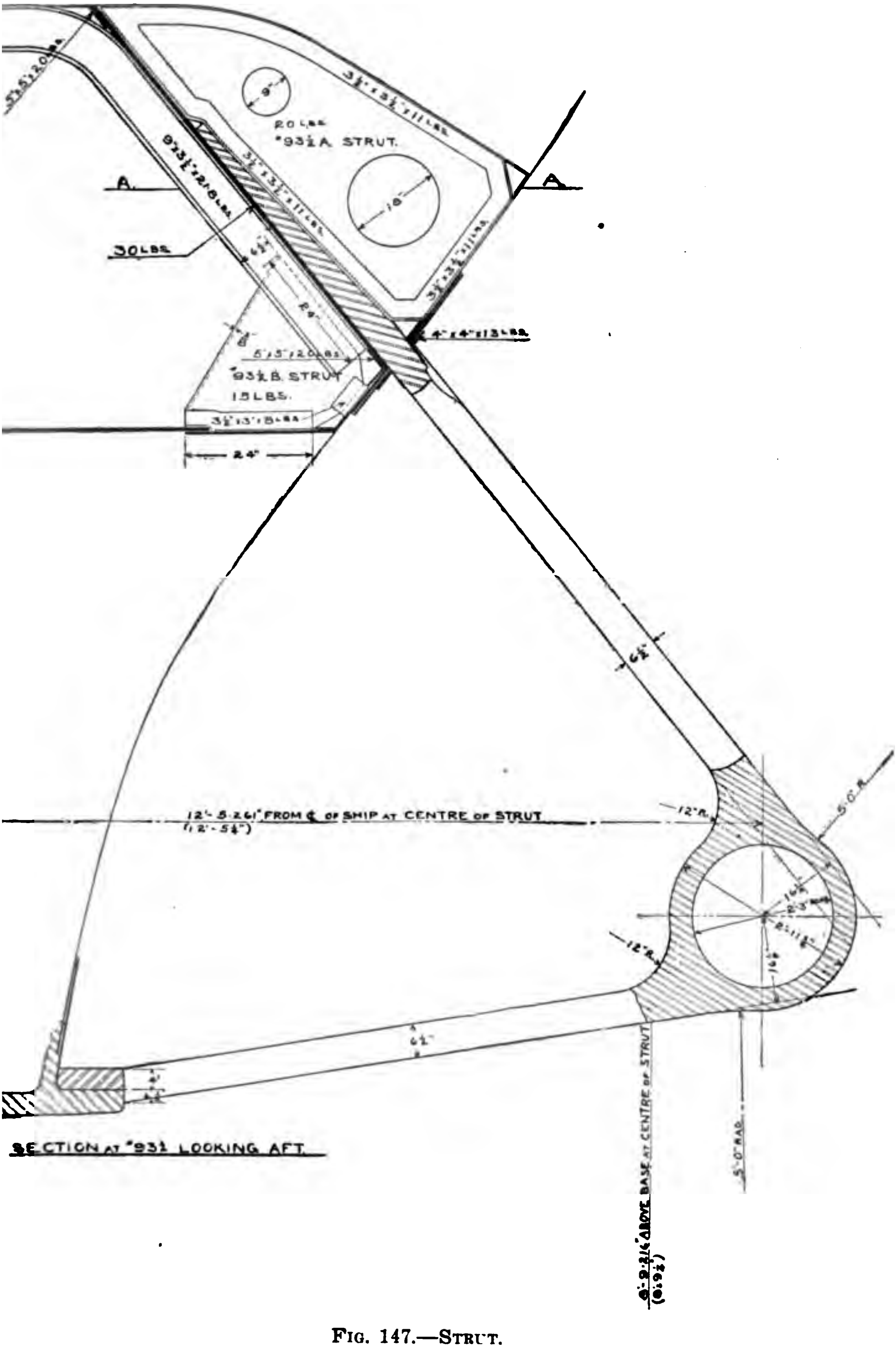


FIG. 147.—STRUT.

Projections are cast on the rudder to bring up on the sternpost when the rudder is hard over, thus limiting the angles to which the rudder may be put; these are generally at 35° either side of longitudinal center line.

Shaft struts.—In twin-screw vessels, a considerable length of the propeller shafting is outside the ship, and struts are fitted on each side immediately forward of the propellers, to take the weight of the propellers, after end of shafting, etc. For steel ships, these struts are of cast steel; in the sheathed ships of the *Denver* class, of manganese bronze. These struts do not have to take any of the fore and aft thrust, which is taken in the engine room by the thrust block, but they have to resist vibration and support a considerable part of the weight, and so the connection requires to be rigid. The arrangement is indicated in Fig. 147.

The arms are flattened out at the top and bottom, the upper palm extends inside the ship, where it is riveted to a heavy fore and aft bracket fitted to receive it. The lower palm is scarphed to fit snugly over a ledge cast on the side of the sternpost proper, at its bottom, to which it is securely fastened by through rivets and tap rivets. The arms of the struts are slightly pear-shaped in section, the blunt end foremost and the after edge sharp, this being the form of least resistance when fully submerged.

The most recent ships have four screws and require struts on each side for two shafts, but as the propellers are smaller the strut arms are much shorter.

The section of the strut indicated in the sketch is somewhat more massive than is present practice, but otherwise there is no essential difference.

CHAPTER XVIII.

ARMOR AND DECK PROTECTION.

Modern warships are liable to three forms of attack: Ramming, torpedo and mine attack, and gun fire. Of recent years, ramming has not been employed much, and the experience of the Russo-Japanese War indicates that in all probability it will not be.

Against ramming and torpedo attack, the protection requires to be provided below the waterline, and has generally taken the form of minute watertight subdivision, though some ships have thin under-water armor distributed in various ways. The protection against mines and torpedoes is still receiving much attention from naval constructors.

The most serious form of attack, however, is the gun fire. As a protection against this, armor is fitted over as large a part of the outside area of the vessel as possible, and over gun positions. Coal is distributed at the sides to assist the armor. The places unprotected by the armor are minutely subdivided near the waterline to localize the damage, and thick decks are fitted, near waterline and above, to protect certain vital parts.

The protection takes two general forms:

(1) Protection to armament and personnel.

(2) Protection of buoyancy and stability.

In a typical U. S. battleship of 16,000 tons, 4014 tons are armor, and of this 1820 tons are for protection to armament, and 2194 tons for protection to buoyancy and stability.

The thickness and distribution of armor varies from class to class, partly due to the change of naval opinion, but more largely due to the increase in knowledge as to the effects of gun fire as the result of actual war experience and elaborate tests and to the development made in the manufacture of guns, projectiles and armor.

An increase in the resisting quality of armor is likely to result in a decrease in armor thickness on contemporary ships, while an increase in the ballistic quality of guns will be reflected in an increase in armor thickness.

The question of armor development arose with the advent of iron-clad vessels for naval use.

The old *Monitor* and *Merrimac* are among the first examples of this type of vessel, but with the improvements in gun manufacture, it became apparent that the wrought iron plates as first used, could not withstand heavy gun fire. As a result a compound armor plate was developed in England and an all steel plate in France. However, in 1889, nickel was introduced in steel and a plate of great toughness and resistance was produced. This type of armor proved superior to the old and from then, onward, the march of progress has increased. In 1890 the Harvey process was advanced, followed in 1895 by the Krupp process.

These two processes are essentially the same in principle and represent the highest development of the compound type of armor.

Formerly, this kind of armor was manufactured by taking a wrought iron plate as a backing and casting upon its face a plate of steel, the former being so heated as to produce as perfect a union as possible. This operation was based on the theory that a plate to resist the powerful energy of a projectile must have a hard face to resist penetration and a tough back to prevent shattering on impact. Difficulty, however, was experienced with the flaking of the steel face, so that a homogenous nickel-steel plate really superseded this type, until the Harvey plate was adopted.

This process was really a step backward; in principle it was based on the compound type, but was its perfection. The Harvey plate was produced by the application of the cementation process to homogenous steel plates. The Krupp process is the same, but owing to a different composition of the steel used, it is susceptible of a greater treatment which improves its ballistic resistance.

The manufacture of a Krupp armor plate consists of a series of distinct operations requiring great care and attention and covers a period of from four to nine months, depending on the thickness of the plate.

The composition of the plate having been determined upon, the necessary elements are melted together in an open hearth furnace. When ready for tapping, the ingot mould having been prepared, the metal is run into a large ladle, from which it is poured into the

mould through a gate on the outside which connects with the interior of the mould at the bottom. The ingot is bottom poured so as to get a more perfect ingot and the large projection on the upper end, the sink-head, is an aid in handling. The mould is made up of cast iron sections bolted together to facilitate the stripping of the ingot. After the ingot has cooled, it is stripped, that is, it is removed from the mould. Usually twenty-four hours suffice for the ingot to solidify and cool sufficiently to permit its being stripped, and then the ingot is sent to the heating furnaces preparatory to forging. The ingot after being heated for about twenty-four hours is taken out of the furnace and receives its first forging. The ingot is placed on a die under a 14,500-ton hydraulic press and there forged to within a few inches of its finished thickness. At each working of the press the metal is decreased about three inches in thickness, the ingot being moved along until its whole length has been forged. Of course, the length and breadth are increased, the metal under such great pressure flowing evenly in all directions, and this operation is repeated until the required dimensions are obtained.

It has been the practice of some manufacturers of armor plate both in this country and abroad to use a series of rolls instead of a press, but it has been proven that the forging of a plate under a hydraulic press effects a more uniform working of the metal and produces a finished plate far superior to one which has been rolled.

After forging, the sink-head is cut off and the plate allowed to cool a little in air before annealing.

From the annealing furnace the plate is taken to be scaled by pneumatic hammers preparatory to carbonizing. This process is that known as the cementation process and consists essentially of heating the plate in the presence of dry carbon or in a gas-carbonizing furnace.

In the dry-carbon process a special dry-carbon furnace is employed; coal is used in the furnace as fuel and the flame passes over the plates, down in front and back under again to the smokestack. Usually several plates are carbonized at the same time, the plates being arranged in pairs. The faces to be carbonized are placed together, separated only by a layer of finely powdered wood and

animal charcoal. The edges are well sealed and the plates are placed in the furnace through the top and lowered on a bed of sand; the whole is then well covered with sand and if more than one pair are carbonized at the same time, they are treated in like manner and placed on top of the first. When all are well protected from contact with the flame, the furnace top is closed and the furnace brought up to the heat. The heat is maintained at a uniform temperature for a considerable length of time, this time depending on the amount of carbon to be absorbed by the plates, and then the furnace is allowed to cool. Almost a month is employed in this process, from the time the plate is charged until it is taken from the furnace.

If the gas-carbonizing process is employed, the plate, with the face to be carbonized exposed, is placed on a bed of sand in a furnace which is heated by some highly carbonized gas. The flues for the flame entry are built on each side of the furnace and so arranged that they can be used alternately, while a deflector causes the flame to first strike the top of the furnace and then pass downward. After the furnace has been raised to heat, coal gas or one rich in hydrocarbons, is passed along the surface of the plate and the intense heat causes this to be broken up, depositing carbon on the face of the plate. The plate is left in the furnace until the required degree of carbonization is attained.

The plate is then again scaled and reheated for its second or final forging to bring it to gage. This forging also serves to smooth up any roughness on the surface. After forging it is again annealed and from the annealing furnace goes to the machine shop, for such machining as can be done preparatory to bending.

On return from the machine shop, the plate is heated preparatory to bending and this operation requires the greatest skill and experience in order to prevent cracking to a degree which would result in the condemnation of the plate. An allowance, too, must be made for any slight distortion which may occur in the next operation, that of tempering and water hardening.

The plate is heated to the required temperature and then subjected to a cold water spray. The bath is of a special design and is arranged to give a pressure of about fifteen pounds per square inch.

The plate is then ready for the inspector. He takes a number of

high-grade punches and goes carefully over the whole carbonized face, testing every square foot for hardness. The punch must be dulled and the surface of the plate show practically no mark. If this test is satisfactory, the coupon, which has been previously cut in the machine shop is broken off to show the structure of the plate by its fracture. Then follows the drill test to show the depth of chill and if the plate passes this test, bars are taken to show its physical characteristics, that is, tensile strength, elastic limit and extension.

After the above tests are completed, the ballistic plate is picked—that is, a plate to be fired at and which represents a group of plates. The armor for a battleship is divided into groups of from 400 to 600 tons, as determined by the Department. This test is the most important and on its acceptance or rejection hangs the fate of the whole group of armor; as a result the inspector usually picks that plate of a group which in his opinion is the least likely to pass.

The plate having been decided on, it is sent to the proving ground for test. Here it is attached to a structure, braced from the rear and bolted in the same manner as armor on shipboard. When in readiness, three shots are fired at it, the actual thickness of the plate determining the gun to be used and the initial velocity. Approximately a gun of the same caliber in inches as the armor in thickness is used and no projectile or fragment thereof shall get entirely through the plate, nor shall any through crack develop to an edge of the plate or to another impact.

The plate having successfully passed test, the group is accepted and the remaining plates are finished machined; of course, a replacing plate is substituted for the ballistic one.

After the plates are finished machined, prior to shipment, they are erected in the shop to insure accuracy of design and continuity of joints, so that they can at once be attached to the ship's structure on arrival at destination.

The building of armored ships of modern type (not including monitors) practically began in the U. S. Service with the construction of the original *Texas* and the original *Maine* in 1889 to 1895. So that in the beginning the United States had, to a certain extent, the benefit of much of the experience of foreign services in the arrangement of guns and distribution of armor.

We may trace the development of this generally, by taking typical ships from the time of the original *Texas* (later *San Marcos*) to the latest type.

San Marcos ex-*Texas*—1889-1895: 301′ 4″ × 64′ 1″ × 22′ 6″ draft; displacement, 6327 tons. The waterline belt armor is 12 inches thick at top and 6 inches at bottom, of Harveyized type; the redoubt is 12 inches thick, the diagonal 8 inches thick, and the turrets 12 inches thick, nickel-steel. (See Fig. 148.)

Here we see the echelon arrangement of turrets, the thick, narrow waterline belt, and the flat protective deck.

Oregon—1890-1896: 348′ × 69′ 3″ × 24′; displacement, 10,163 tons. The waterline belt is 18 inches at top and 8½ inches at bottom; the diagonal armor is 14 inches thick; the casemate side and diagonal, 4 inches; the 13-inch barbettes are 17 inches, the 8-inch barbettes, 8″-6″; the 13-inch turrets are 15 inches, the 8-inch turrets, 6 inches thick. The waterline belt and turrets are of Harveyized type, and the remaining armor nickel-steel. (See Fig. 149.)

Iowa—1893-1897: 360′ × 72′ 2½″ × 23′ 10⅝″ draft; displacement, 11,275 tons. The waterline belt is 14 inches thick at top, 7 inches at bottom, 14 inches at waterline; the diagonal armor is 12 inches; the casemate is 4 inches; the 12-inch barbettes are 15 inches and 12½ inches thick; the 8-inch barbettes are 8 inches and 6 inches thick; the 12-inch turrets are 17 inches and 15 inches thick; the 8-inch turrets are 8 inches and 7 inches thick. The armor is of the Harveyized type. A flat protective deck is fitted at the third deck level amidships, and at the upper platform level, forward and aft. Here is seen an increase in freeboard forward, adding to the weatherly qualities of the vessel. (See Fig. 150.)

Kearsarge—1896-1900: 368′ × 72′ 2½″ × 23′ 10½″ draft: displacement, 11,724 tons. The waterline belt is 16½ inches thick at top, 9½ inches at bottom, and 13¾ inches at waterline, reduced to 4 inches thick forward; the triangular and athwartship is 12 inches; the casemate is 5 inches at side and 4 inches athwartship; the superstructure armor is 6 inches; the barbettes are 15″-12½″ thick; the turrets, 17″-15″-11″-9″ thick. The armor is of the Harveyized type. The protective deck is flat amidships, sloping at ends. This is the first type of battleship with superposed turrets, and we again see the low freeboard of the earlier *Oregon* class. (See Fig. 151.)

Alabama—1896-1900: 368′ × 72′ 2½″ × 23′ 8½″ draft; displacement, 11,703 tons. The waterline belt is 16½ inches at top, 9½ inches at bottom, 13⅜ inches at waterline, tapering to 14″-11½″-9″-6½″-4″ at top, and to 8″-6¾″-5½″-4¾″-4″ at bottom, forward; the triangular armor is 12 inches; the lower and upper casemate is 5½ inches at side and diagonal; the gun protection on superstructure is 6 inches; the barbettes are 15″-10″ thick; the turrets are 14 inches thick. The armor is of the Harveyized type. The protective deck is flat amidships and sloping at ends. In this type the 8-inch gun has been abandoned and the intermediate battery made of a uniform size of 6 inches. The relatively high freeboard forward again appears. (See Fig. 152.)

Maine—1898-1902: 388′ × 72′ 2½″ × 23′ 9″ draft; displacement, 12,846 tons. The waterline belt is 11 inches thick at top, 7½ inches at bottom, 11 inches at waterline, tapering to 9″-7″-5″-4″ at ends; the lower and upper casemate sides and athwartship are 6 inches; the gun protection on superstructure is 6 inches; the barbettes are 12″-8″ thick; the turrets are 12″-11″ thick. The armor is of the Krupp type, considerably increasing its resisting qualities. The protective deck is flat amidship and sloping at ends. (See Fig. 153.)

Virginia—1902-1906: 435′ × 76′ 2½″ × 23′ 9″ draft; displacement, 14,948 tons. The waterline belt is 11 inches thick at top, 8 inches at bottom, 9 inches at waterline, tapering to 6″-5″-4″ at ends; the triangular armor is 6 inches; the lower and upper casemate at side and athwartship is 6 inches; the barbettes for superposed turrets are 10″-7½″ thick, and the 8-inch broadside barbettes are 6″-4″ thick; the superposed turrets are 12″-8″-6″, and the broadside turrets are 6½″-6″ thick. The armor is of the Krupp type. The protective deck is sloping at sides and ends. This class also has the superposed turret arrangement and a continuous high freeboard. (See Fig. 154.)

Connecticut—1903-1906: 450′ × 76′ 10″ × 24′ 6″ draft; displacement, 16,000 tons. The waterline belt is 11 inches thick at top, 9 inches at bottom, 11 inches at waterline, tapering to 9″-7″-5″-4″ at ends; the triangular armor is 6 inches; the lower casemate at side and athwartship is 6 inches; the upper casemate at side and athwartship is 7 inches; the 12-inch barbettes are 10″-7½″-6″ thick, and the

19

8-inch barbettes are 6″-4″-3¾″ thick; the 12-inch turrets are 12″-8″ thick, and the 8-inch turrets are 6½″-6″ thick. The armor is of the Krupp type. The protective deck is sloping at sides and ends. (See Fig. 155.)

South Carolina—Beginning the dreadnought type, *i. e.*, all main battery guns of same calibers—1906-1909: 450′ × 80′ 2⅝″ × 24′ 6″ draft; displacement, 16,000 tons. The waterline belt is generally 11 inches thick at the top, tapering uniformly to 9 inches thick at the bottom. In way of the magazines, however, this is increased to 12 inches at the top and 10 inches at the bottom. The triangular armor is 11 inches thick, athwartship armor 10 inches thick. The casemate armor is 8 inches thick at the top and 10 inches thick at the bottom, uniformly tapered. The athwartship casemate armor is 8 inches thick throughout. The 12-inch barbettes are 10 inches and 8 inches thick. The 12-inch turrets are 12 inches and 8 inches. The armor is of the Krupp type. The protective deck is flat throughout its length, and is dropped one deck forward of the No. 1 turret and over the torpedo room. (See Fig. 156.)

Delaware—1907-1910: 510′ × 85′ 2⅝″ × 27′ draft; displacement 20,000 tons. The waterline belt is 11 inches thick at the top, tapering to 9 inches thick at the bottom. The triangular and athwartship armor is 10 inches thick. The lower casemate armor is 8 inches thick at the top and 10 inches thick at the bottom, uniformly tapered; athwartship armor is 9 inches thick. The upper casemate and diagonal armor is uniformly 5 inches thick. The 12-inch barbettes are 10 inches, 8 inches and 4 inches thick. The 12-inch turrets are 12 inches and 8 inches thick. The armor is of the Krupp type. The protective deck is flat throughout its length, and is dropped one deck forward of the No. 1 turret and over the torpedo room. (See Fig. 157.)

Florida—1909-1911: 510′ × 88′ 2⅝″ × 28′ 6″ draft; displacement, 21,825 tons (two-thirds full supply of stores and fuel, and full supply of ammunition). The waterline belt is 11 inches thick at the top and 9 inches thick at the bottom, uniformly tapered. The triangular athwartships armor is 10 inches thick. The main belt athwartships armor is 10 inches thick. The lower casemate athwartships arms is 9 inches thick. The upper casemate and diagonal

armor is 6½ inches thick. The 12-inch barbettes are 10 inches, 8 inches, and 4 inches thick. The 12-inch turrets are 12-inches and 8 inches thick. The armor is of the Krupp type. The protective deck is flat throughout its length, and is dropped one deck forward of the No. 1 turret, and aft of the No. 5 turret. (See Fig. 158.)

Wyoming—1909-1912: 554′ × 93′ 2⅝″ × 28′ 6″ draft; displacement, 26,000 tons (two-thirds full supply of stores and fuel, and full supply of ammunition). The waterline belt is 11 inches thick at the top and 9 inches thick at the bottom, uniformly tapered. The lower casemate armor is 11 inches thick at the bottom, tapered uniformly to 9 inches thick at the top, and the amidship section is 11 inches thick at the bottom, tapered uniformly to a thickness of 9 inches at a height of 9 feet above the lower edge of the lower casemate armor. The triangular athwartship armor is 7 inches thick. The upper casemate and diagonal armor is 6½ inches thick. The athwartship armor is 10 inches thick. The main belt athwartship armor is 8 inches thick. The 12-inch barbettes are 11 inches, 9 inches, and 4½ inches thick. The 12-inch turrets are 12 inches and 8 inches thick. The armor is of the Krupp type. The protective deck is flat throughout its length, and is dropped one deck forward of the No. 1 turret and aft of the No. 6 turret. (See Fig. 159.)

Texas—1911-1914: 565′ × 95′ 2⅝″ × 28′ 6″ draft; displacement, 27,000 tons (two-thirds full supply of stores and fuel, and full supply of ammunition). The waterline belt is 10 inches thick at the bottom and 12 inches thick at the top, uniformly tapered. The lower casemate armor is 11 inches thick at the bottom, tapered uniformly to 9 inches thick at the top, and the amidship section is 11 inches thick at the bottom, tapered uniformly to 9 inches thick at a height of 9 feet above the lower edge. The upper casemate and diagonal armor is 6½ inches thick. The triangular athwartship armor is 7 inches thick. The lower casemate athwartship armor is 10 inches thick; and the forward athwartship armor is 11 and 10 inches thick. The main belt athwartship is 9 inches thick. The 14-inch barbettes are 12 inches, tapered to 10 inches, 7 inches, and 5 inches, tapered to 4 inches thick. The 14-inch turrets are 14 inches, 9 inches, and 8 inches thick. The armor is of the Krupp type. The protective deck is flat throughout its length, and is

dropped one deck forward of the No. 1 turret, and aft of the No. 5 turret (See Fig. 160.)

Nevada—1912-1915: 575′ × 95′ 2⅝″ × 28′ 6″ draft; displacement, 27,500 tons (two-thirds full supply of stores and fuel, and full supply of ammunition). The main belt armor is 13½ inches thick from its top to 2 feet below the designer's waterline, whence it is tapered uniformly to 8 inches thick at the bottom. Aft of the main belt the armor is 13 inches thick. The forward athwartship armor and aftermost armor bulkhead is 13 inches thick. The athwartship armor aft is 13 inches. The 14-inch barbettes are 13 inches and 4½ inches thick. The 14-inch 3-gun turrets are 18 inches and 9 inches thick. The 14-inch 2-gun turrets are 16 inches and 9 inches thick. The armor is of the Krupp type. The protective deck is sloping at sides and is dropped one deck forward of the No. 1 turret, and aft of the No. 4 turret. (See Fig. 161.) The second or upper protective deck appears.

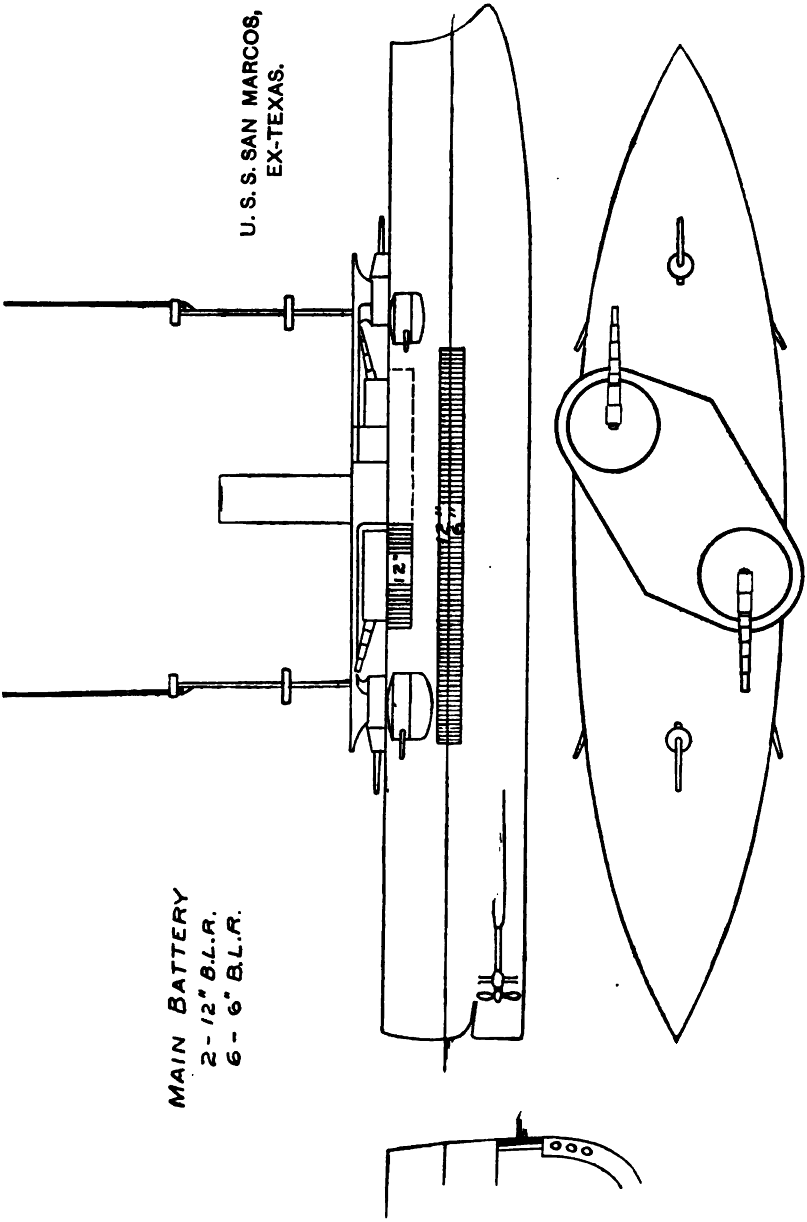


FIG. 148.

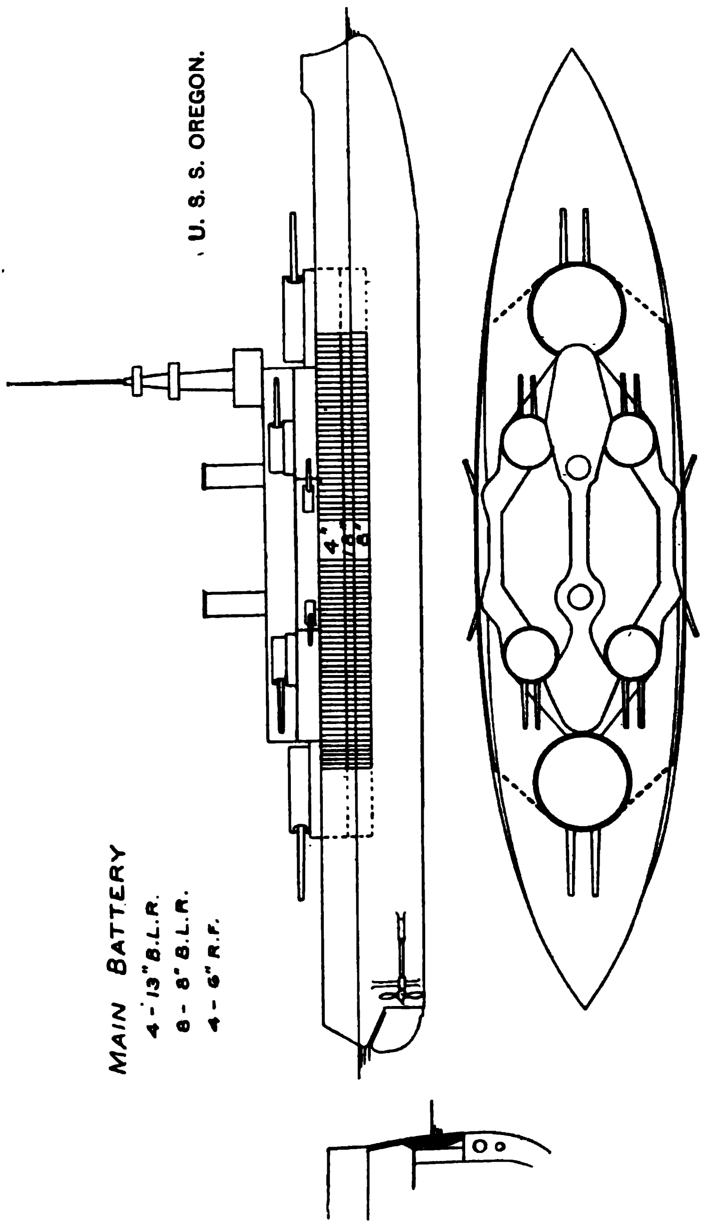


FIG. 149.

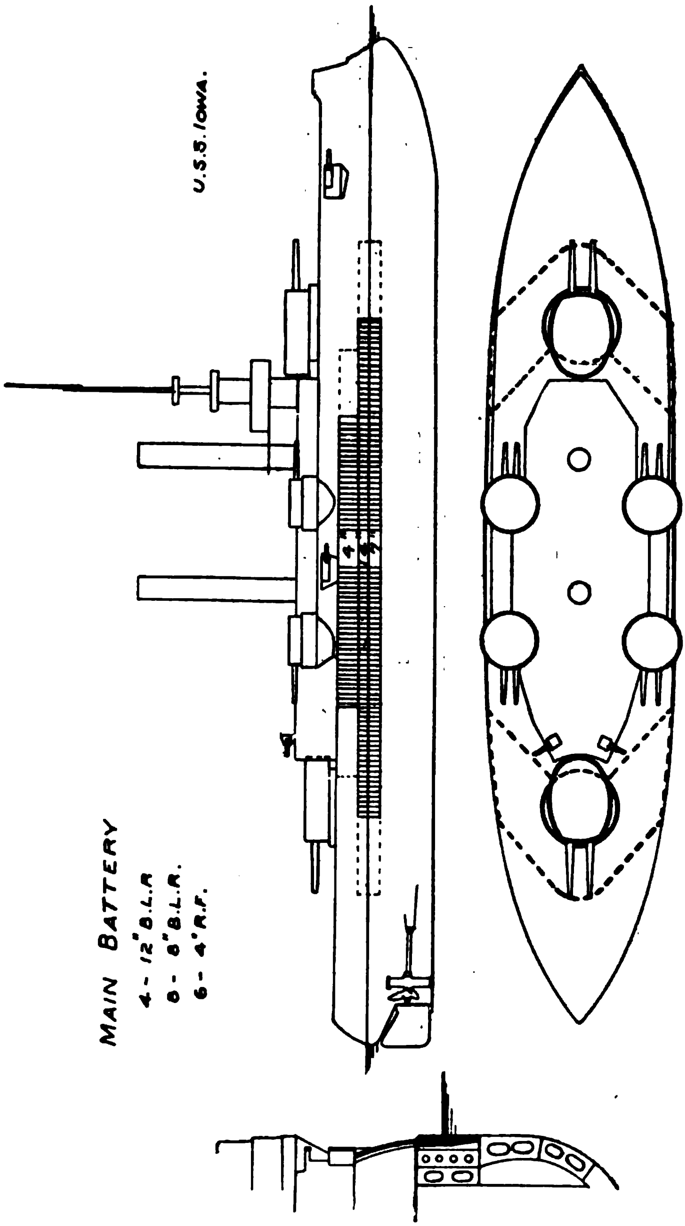


FIG. 150.

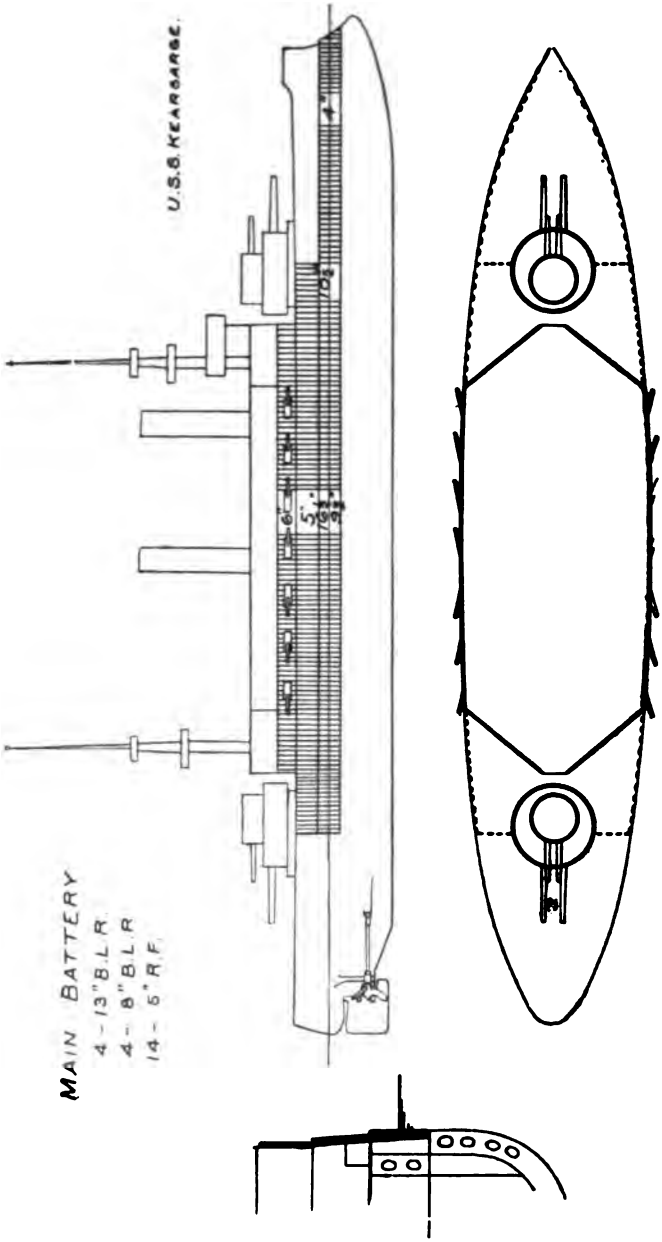


FIG. 151.

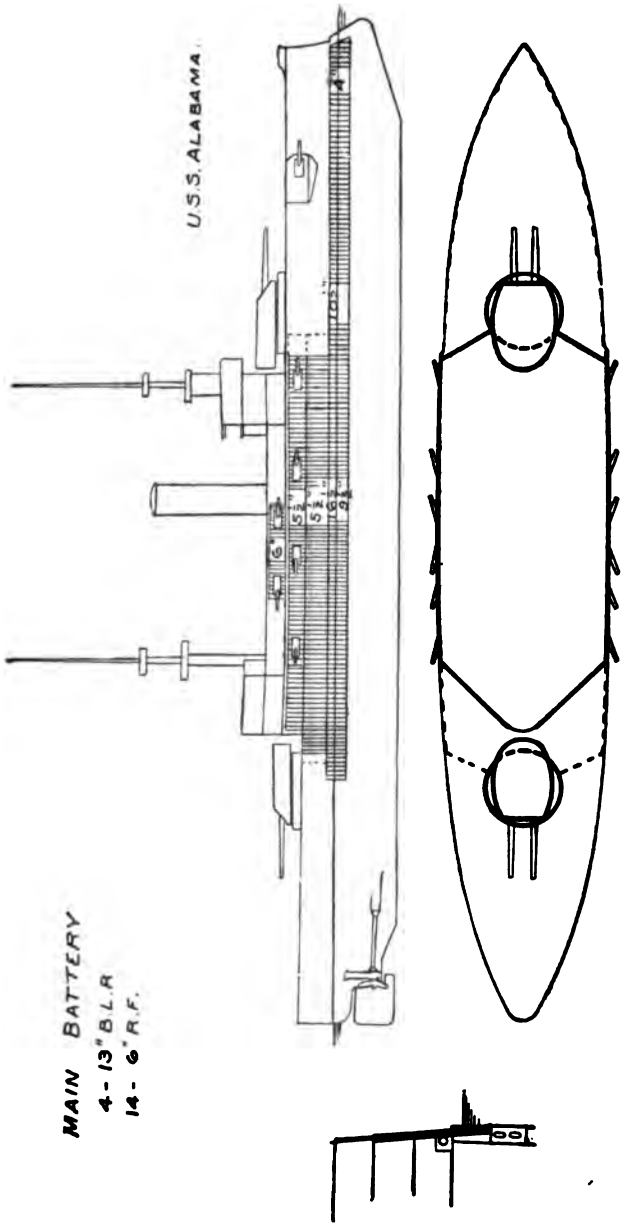


FIG. 152.

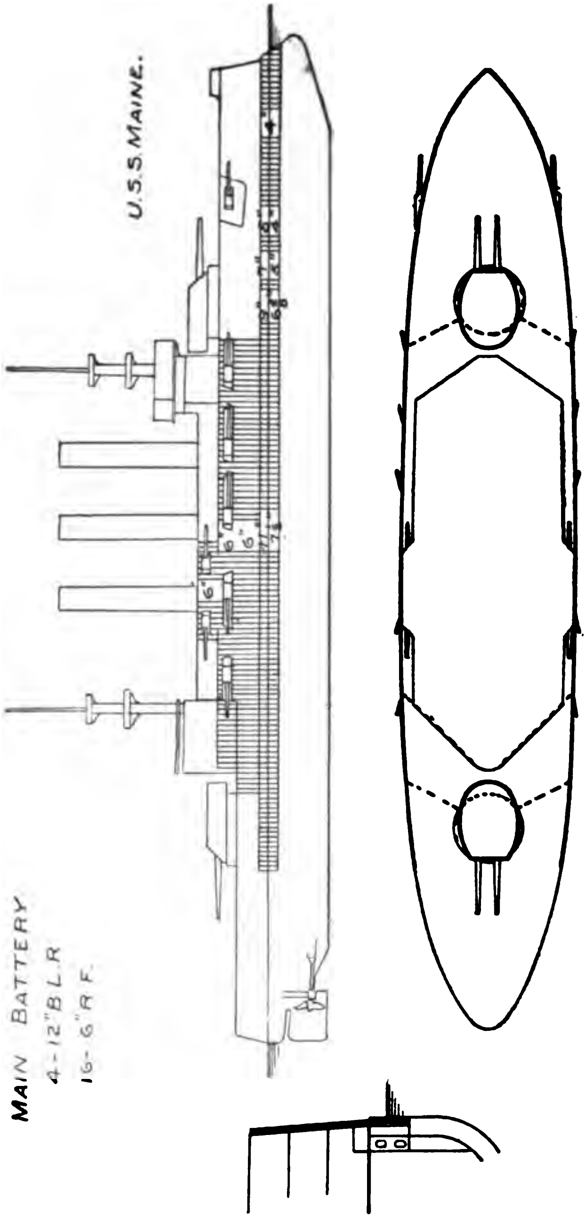


FIG. 153.

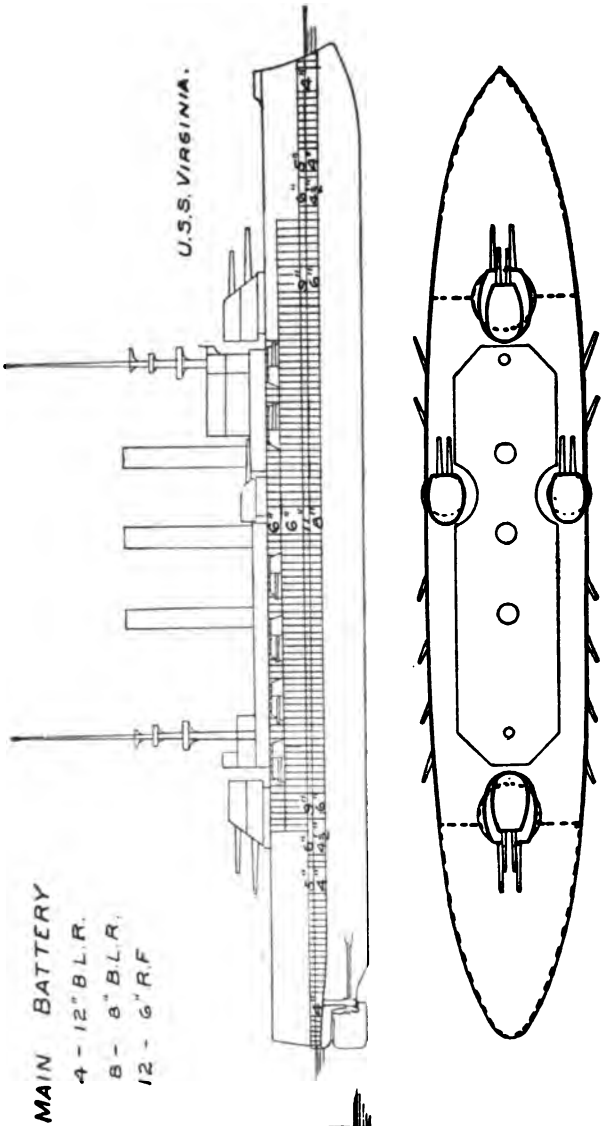
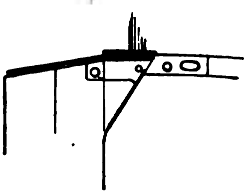


FIG. 154.



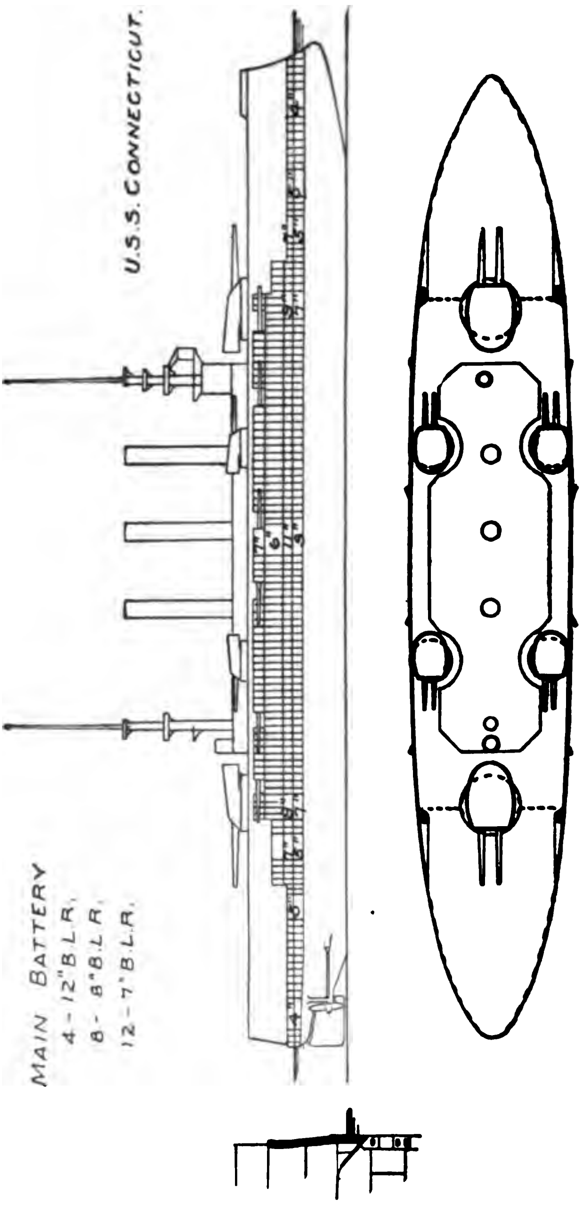


FIG. 155.

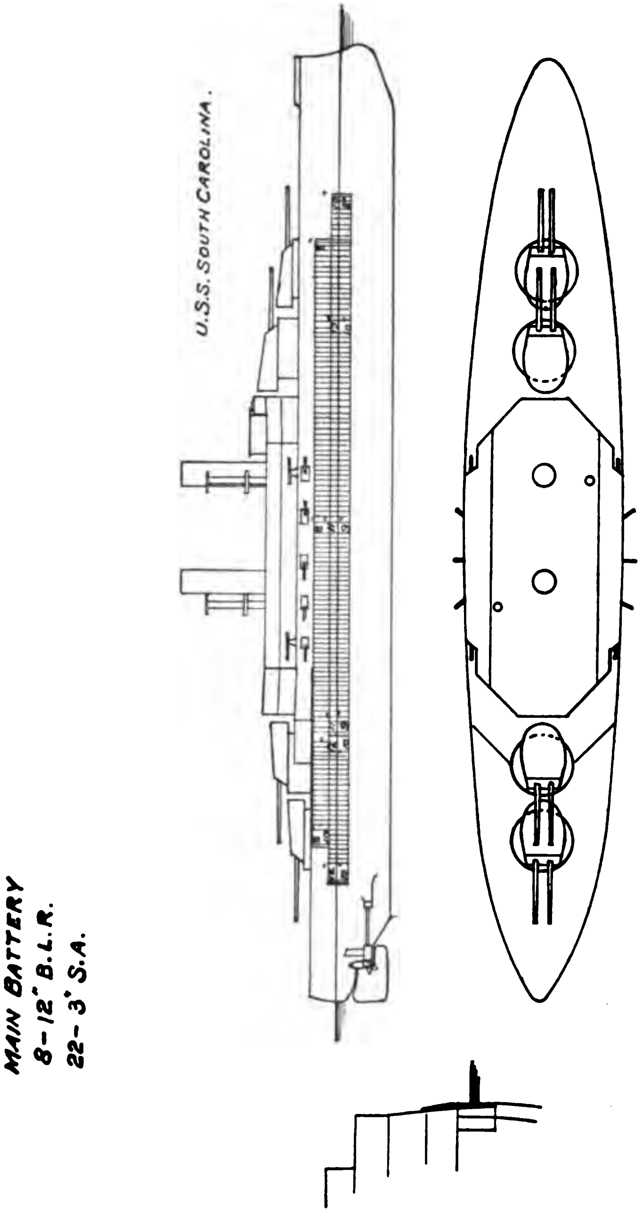


FIG. 156.

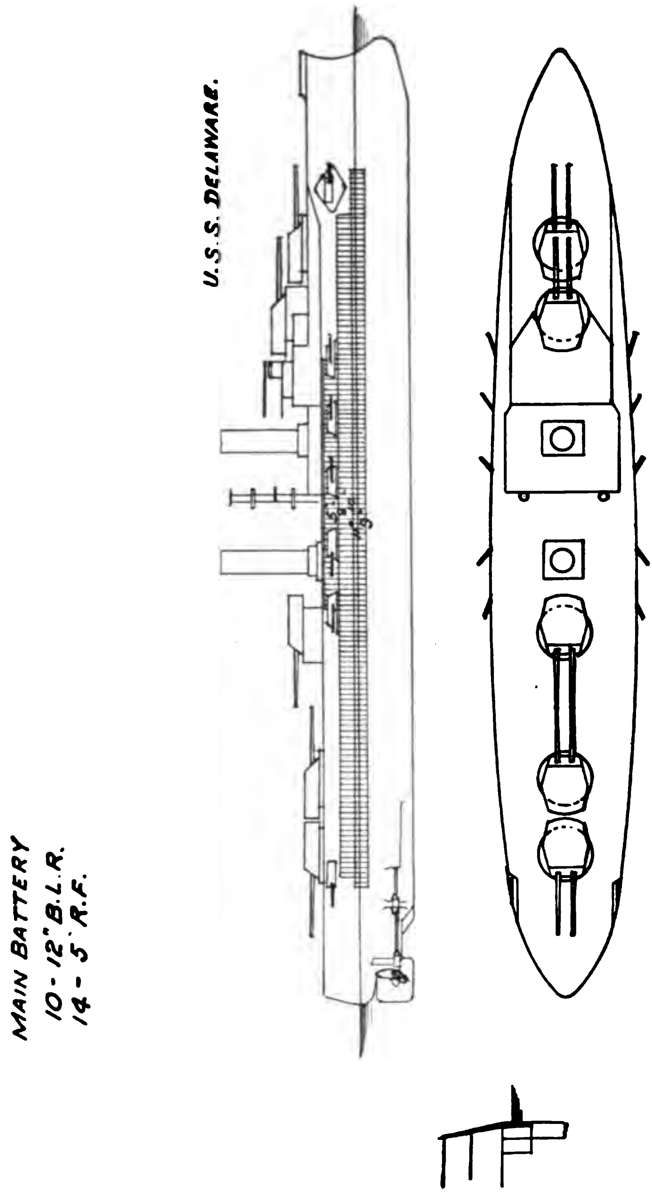


FIG. 157.

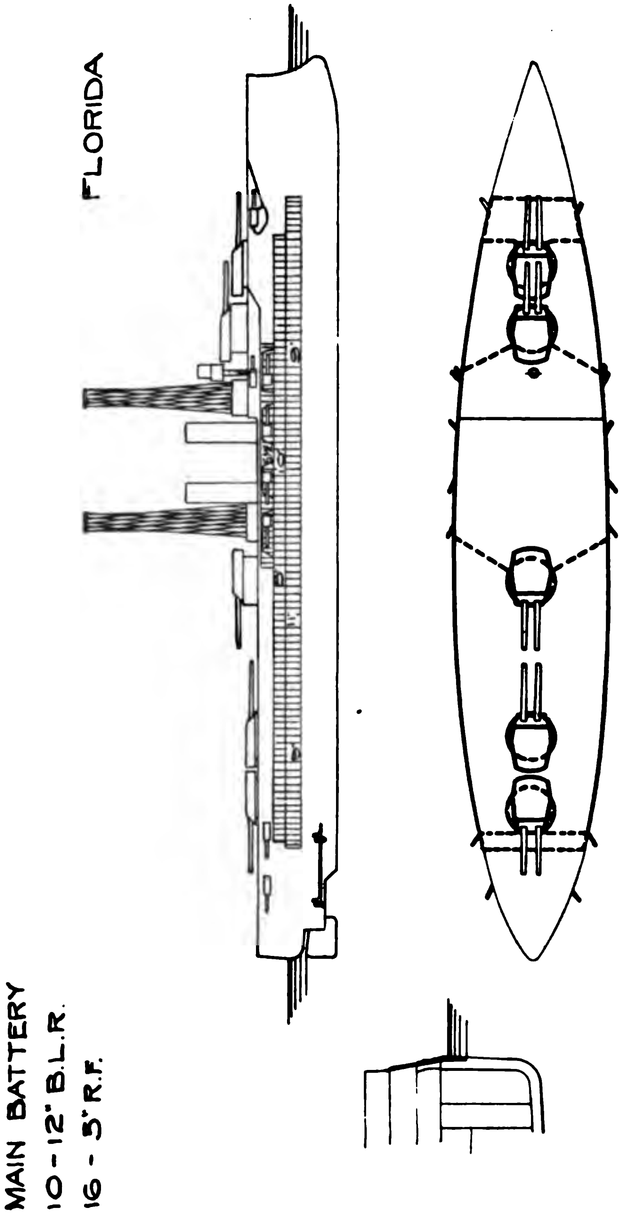


FIG. 158.

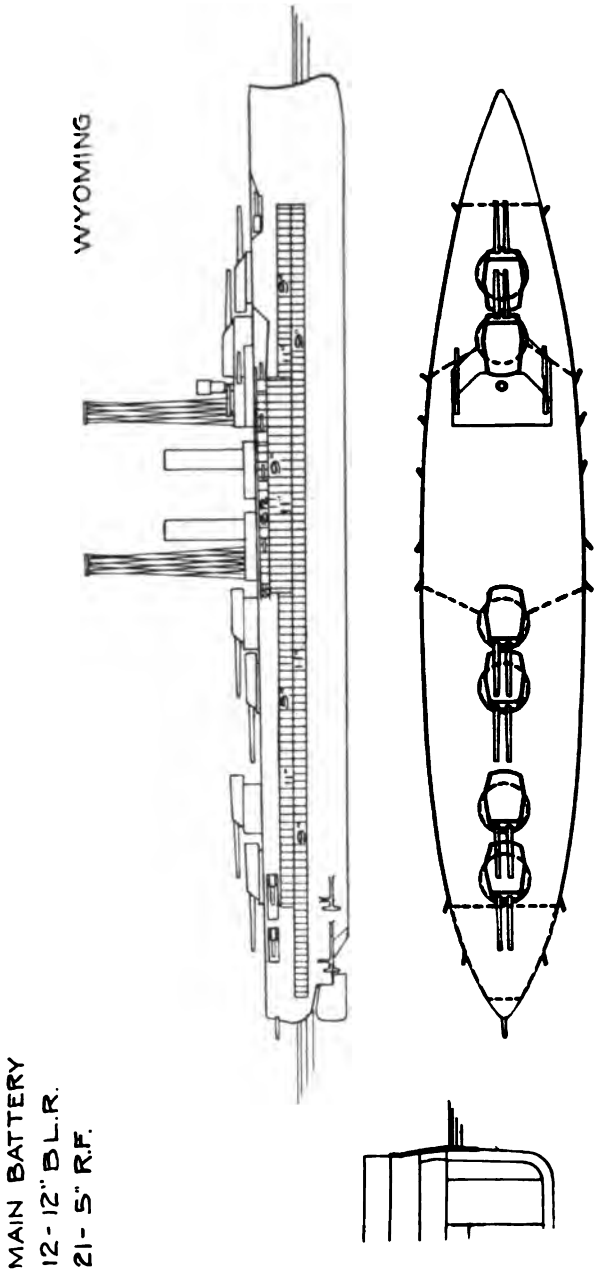


FIG. 159.

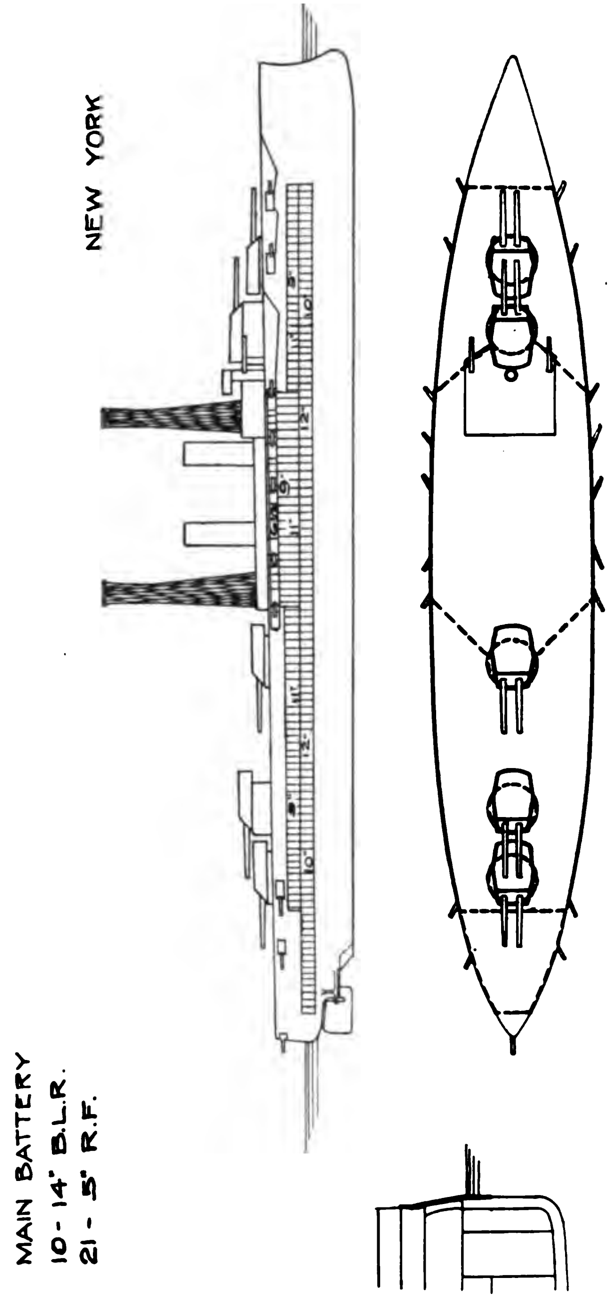


FIG. 160.

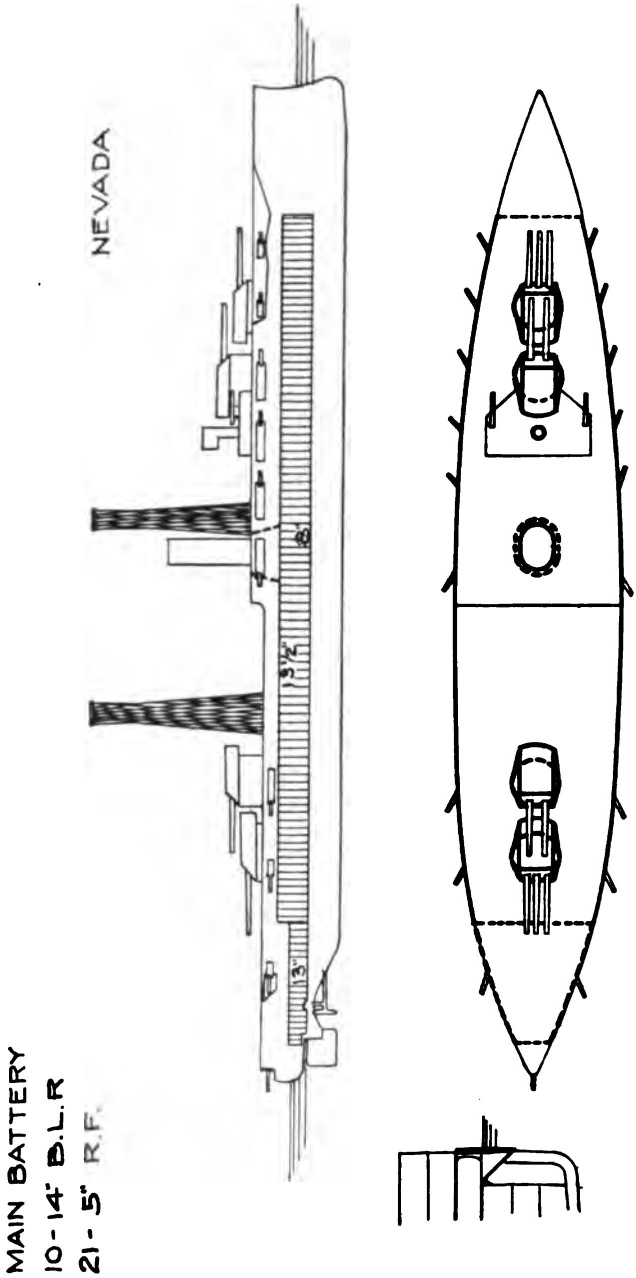


FIG. 161.

Armor Hatches, Gratings, Etc.

In protective decks, many openings are necessary for access to spaces below, etc., which require to be closed in action. Such openings are usually closed by hinged covers, having the same thickness as the adjoining deck. Such hatches are operated by hand

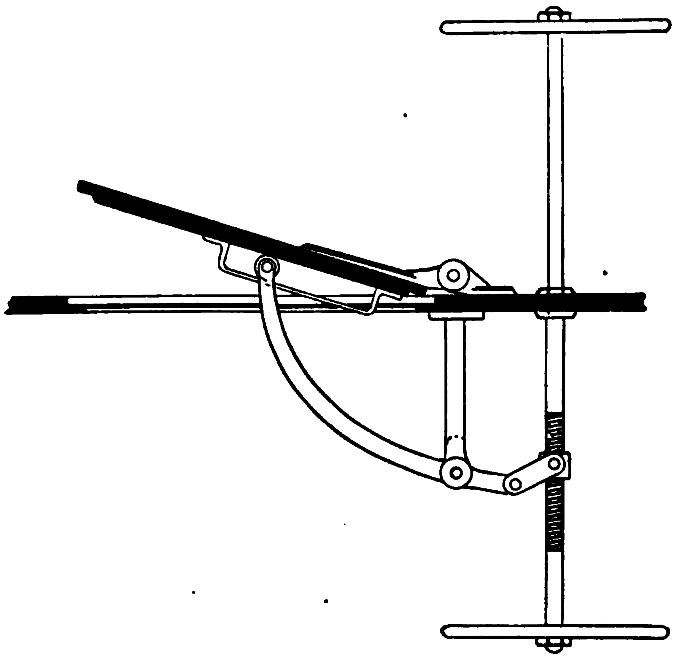


FIG. 162.—SKETCH OF HATCH OPERATED BY SCREW GEAR.

screw gears, electric power, or on the balanced system. Types of the screw gears and balanced system are shown respectively in Figs. 162 and 163, and the electric type is essentially the screw type operated by an electric motor.

A number of the openings in the protective deck require to be open even in action, such as openings for smokestacks, ventilators, etc., and into these armor gratings are fitted. A type of such gratings is shown in Fig. 164.

The opening is divided into rectangular spaces by girders, and into each of these spaces, gratings are fitted. The bars are supported as shown, and for a 1½-inch deck, are 6 inches deep by 1 inch thick. In some cases the bars are fitted on an incline instead of vertically.

Some of these gratings require to be lifted for access to below, and the sections requiring to be lifted are then hinged and fitted with a rope hoisting device, and by winding up the rope on a drum, the grating hatch is raised as required.

Cofferdams.

Around the sides of the ship, extending behind armor, from protective to third deck, and outside of limits of armor to some 3 feet

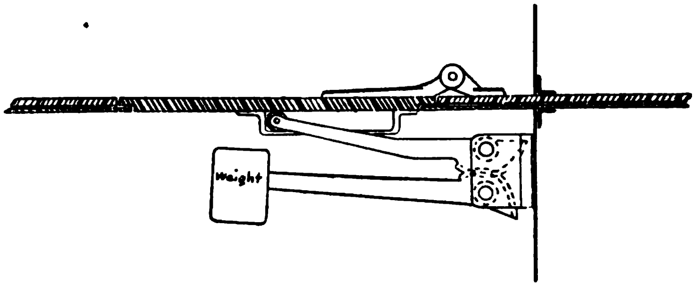


FIG. 163.—SKETCH OF BALANCED HATCH.

above third deck, are fitted hollow watertight boxes about 30 inches in depth from side of ship, called *cofferdams*. These are filled with cellulose, made from corn-pith, fireproofed, and compressed in blocks to a density of 8 pounds per cubic foot. When water gains access to these spaces, the cellulose swells up, closing the opening and preventing further flooding. In the most recent practice the use of such cofferdams has been largely abandoned.

Protection of Cruisers.

The principal qualities to be obtained in a cruiser are high speed and large coal capacity. This necessarily limits the weight available for protective purposes.

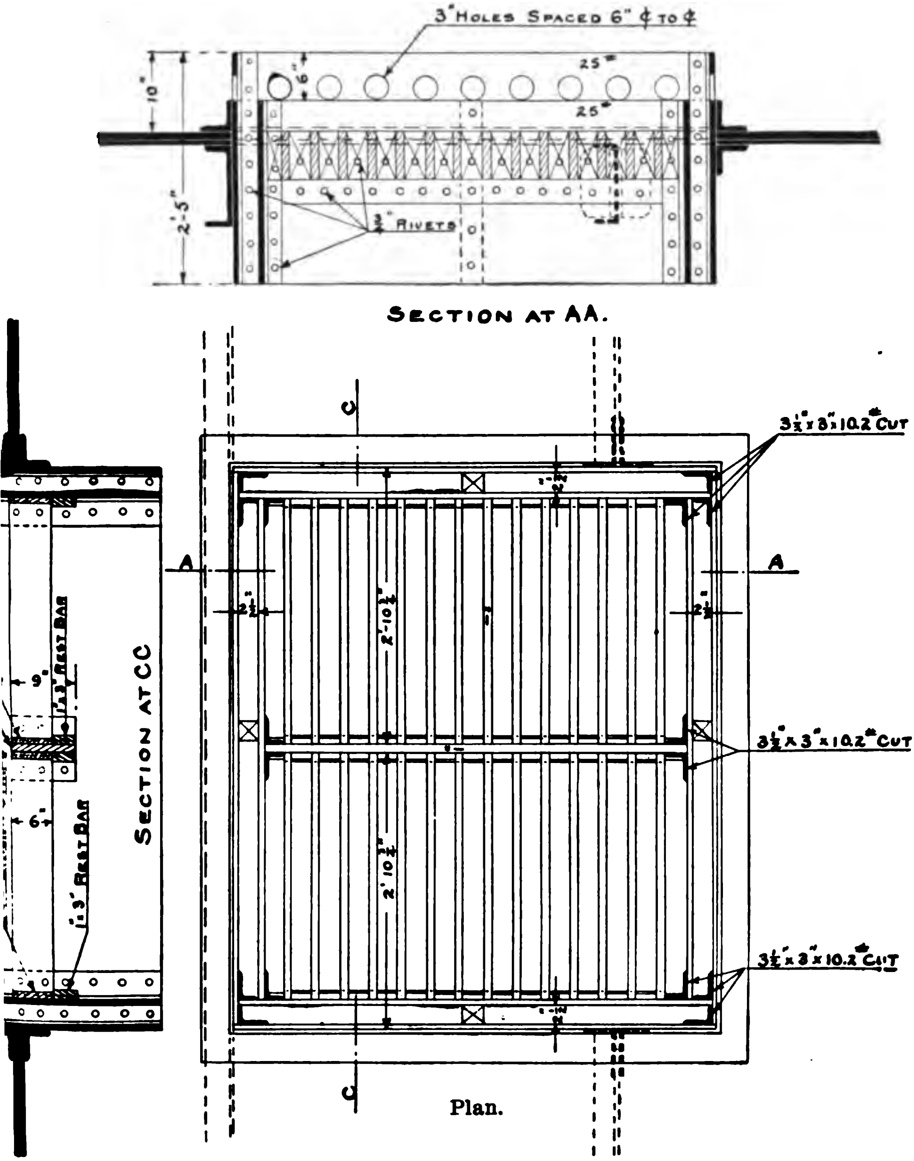


FIG. 164.—ARMOR BAR HATCH IN PROTECTIVE DECK.

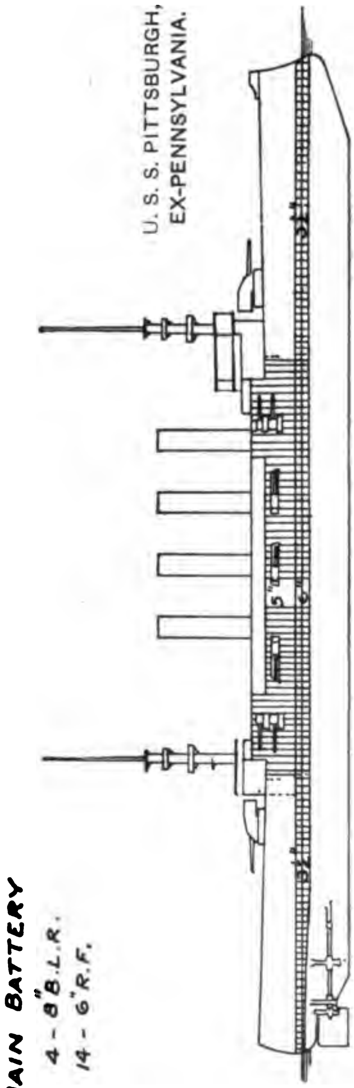
The early cruisers of the U. S. Service, from the time of the *Boston,* had no protection, except a protective deck and that given by coal, and isolated protection to gun positions.

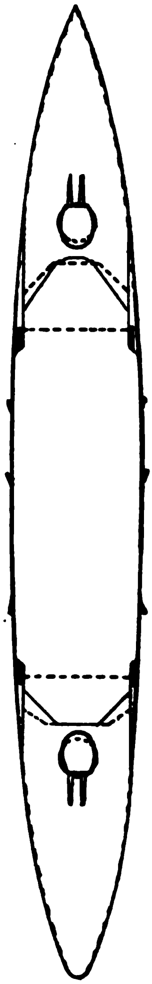
The *New York,* now *Saratoga,* had a narrow waterline belt of 4-inch armor, 8 feet wide, extending over about one-half the length, and a sloping protective deck varying in thickness from 2½ to 6 inches. This, with the armor for gun positions, constituted the armored protection.

The *Brooklyn* was of the same general type so far as concerns protection.

A narrow belt of this kind is apt to be entirely submerged when the ship rolls.

The *Pennsylvania,* now *Pittsburgh,* class of armored cruisers, and the *Washington* and *North Carolina* class, represent later ideas, and by examining Figs. 165, 166, and 167 we see that the distribution of protection is very similar to that on a battleship, though not so thick. Here we find, in the case of the *Pennsylvania,* now *Pittsburgh,* a complete waterline belt of armor 6 inches thick at top and 5 inches at bottom, for a length of about 232 feet abreast the engines and boilers, and of a uniform thickness of 3½ inches forward and aft of these spaces, to bow and stern; a lower and upper casemate 5 inches thick at sides and 4 inches thick athwartships; the barbettes 6 inches thick, and the turrets 6½″-6″. In the case of the *Washington,* a complete waterline belt of armor 5 inches thick for a length of about 330 feet abreast the machinery and magazine spaces, and 3 inches thick forward and aft of these spaces, to bow and stern; a lower and upper casemate 5 inches thick at side and athwartship; the barbettes 7″-4″ thick, and the turrets 9″-7″-5″. In the case of the *North Carolina,* a complete waterline belt of armor, 5 inches thick for a length of about 334 feet abreast the machinery and magazine spaces, and 3 inches thick forward and aft of these spaces, to bow and stern; a lower and upper casemate 5 inches thick at side and 6 inches athwartships; the barbettes 8″-6″-4″ thick, and the turrets 9″-7″-5″.





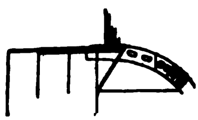


FIG. 165.

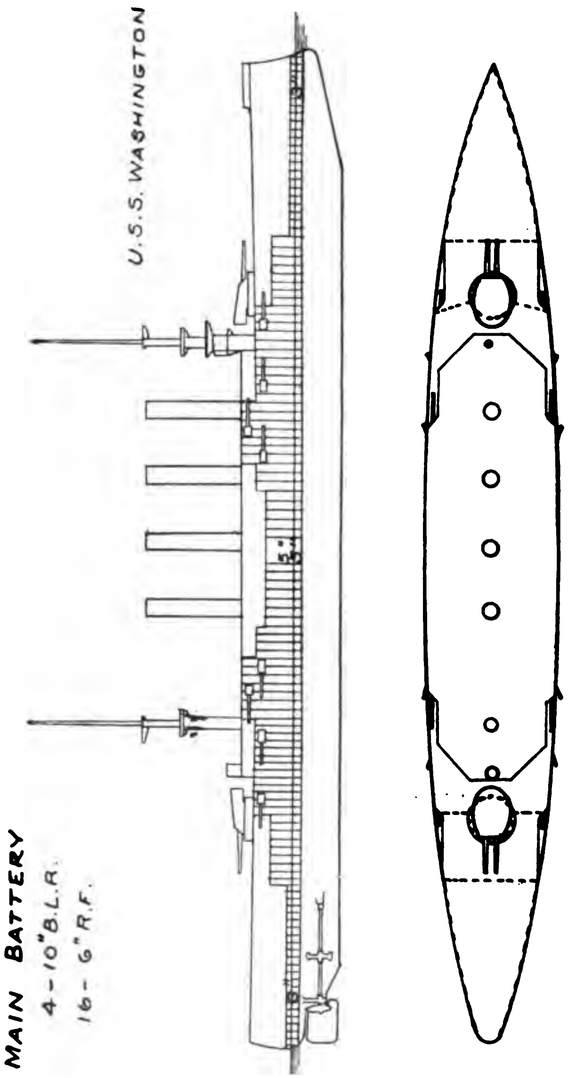
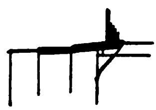


FIG. 166.



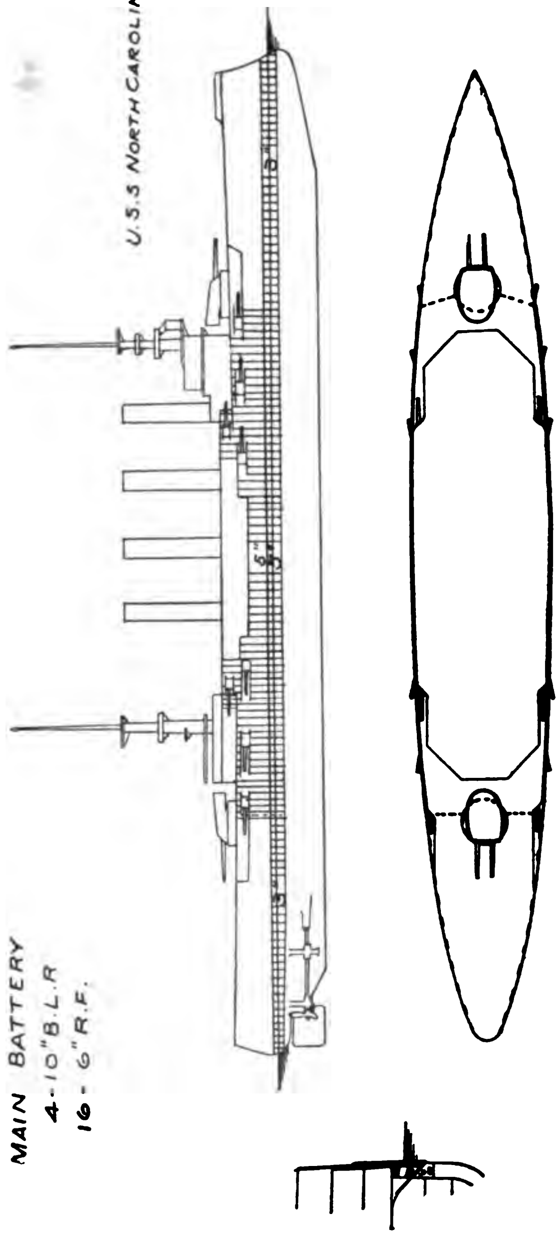


FIG. 167.

Armor Backing and Supports.

In the early days of iron armor, such as was fitted on our early monitors, the wood backing was made very thick, the idea being to provide a support with proper elasticity. The thickness of backing was about equal to and sometimes greater than the thickness of armor.

Modern armor plates prove to offer the greatest resistance when provided with a rigid support, so that wood backing has been reduced to a thickness of 2½ or 3 inches, sufficient to form a bed for the back of the plate and to permit any irregularities of manufacture of plate to be taken up on the backing and still get an even bearing over the whole surface of the plate.

In our earlier ships, the skin behind armor was in two thicknesses, one thickness acting as butt and seam straps for the other. In recent ships this has been changed to one thickness, fitted with butt straps on inside and continuous seam straps on outside. In the most recent ships all armor butts above five inches in thickness are keyed.

The earlier barbettes were "supported" by an entire cylindrical structure, but in the later ships, are supported by the resistance offered by their circular shape, the fastenings at the decks through which they pass, the interior backing rings and keys inserted in the butts of plates.

Behind armor, in spaces where the crew would be called upon to be in action, mantlet plates fastened to the inside of frames by slot-headed screws, are fitted to prevent rivet and bolt heads from flying when the armor is struck.

Armor Bolts.

The earliest form of armor was fastened by through bolts with conical countersunk heads flush on outer surface. When face-hardened armor appeared, the through holes were found to lead to cracks when struck, so that all bolts are now screwed into the back of the plate. One bolt is fitted to every five square feet. This is done so that even if the plate is badly cracked, fragments will not fall off.

The form of armor bolt and washer has undergone several changes in the U. S. Service, but the latest form is shown in Figs. 168 and

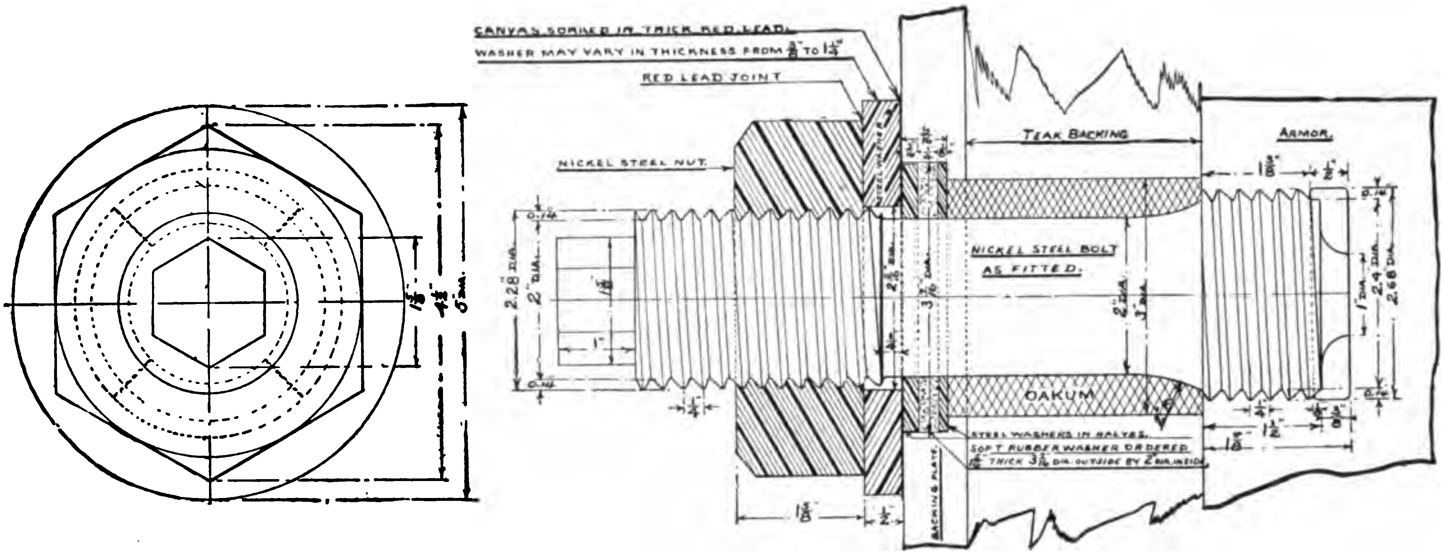


FIG. 168. —SIDE ARMOR BOLT.

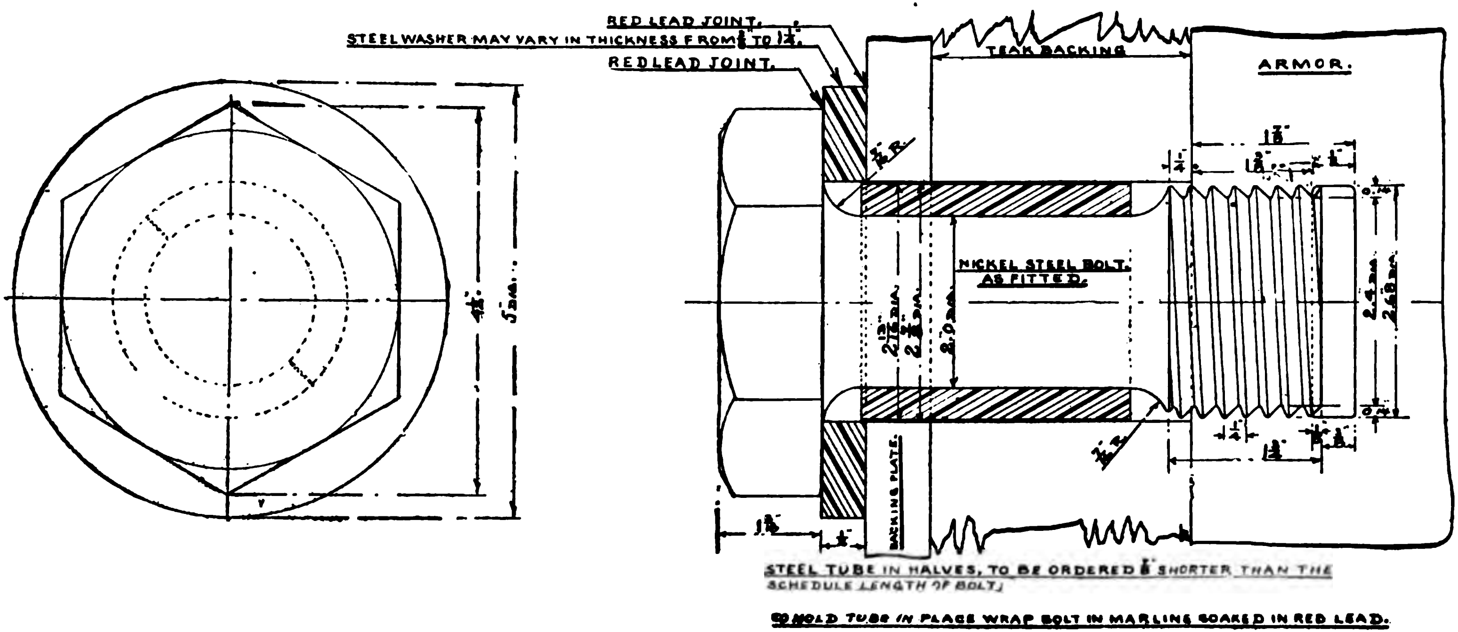


FIG. 169.—TURRET ARMOR BOLT.

169. The shank of the bolt is slightly less in diameter than bottom of thread. This is done to prevent breaking under the thread.

The form of thread has been carefully considered. A counterbore is made in the backing plate, in which, for purposes of watertightness, are fitted, as shown, *1st,* steel washers in halves; *2d,* rubber washers; *3d,* steel split washers in halves; then a canvas gasket seated in red lead; then a plate washer; then the nut.

The type with head, shown in Fig. 169, is that used in barbettes and turrets where the space is limited, and in the side and athwartship armor above gun deck.

CHAPTER XIX.

AUXILIARY MACHINERY, DRAINAGE, FLOODING, AND PUMPING.

Although ordinarily treated in a book of this character, in order not to duplicate the student's work, the author omits touching on such auxiliary machinery as is covered in the other text-books which form a part of the course at the Naval Academy. This includes steering gears, capstans, turret-turning machinery, ammunition hoists, and auxiliaries used in connection with hoisting ammunition. It should be noted, however, that the latest types of boat cranes, deck winches, steering gears and capstans, are electrically operated.

Boat cranes, for ships up to the Michigan class.—These are built-up cranes of box section, formed of plates and angles. The weight of crane is carried by a roller bearing at main deck level, with a guide bearing at the deck above this, and a step bearing at the deck below for the heel of the crane. A platform attached to the crane revolves with it and carries on it two electric motors, one of about 30 horse-power for rotating, and one of 50 horse-power operating a winch for hoisting the boats, each with suitable controlling apparatus. This hoisting winch is fitted with two brakes, one mechanical and one electrical, to prevent dropping the boat from any cause. The character of such a crane is shown in Fig. 170.

The recent ships have a crane of the pillar type, consisting of a collapsible jib revolving around a post which is also a search-light support. The whole is actuated by electricity similarly to the other type of crane referred to. See Fig. 171.

Deck winches.—The latest type of deck winch is also operated by an electric motor, but mechanically it does not differ essentially from the steam-driven type.

In the recent coal burning ships coaling engines have been provided, located behind armor, operating through suitable shafting and gearing, the coaling gypsies located above the weather deck.

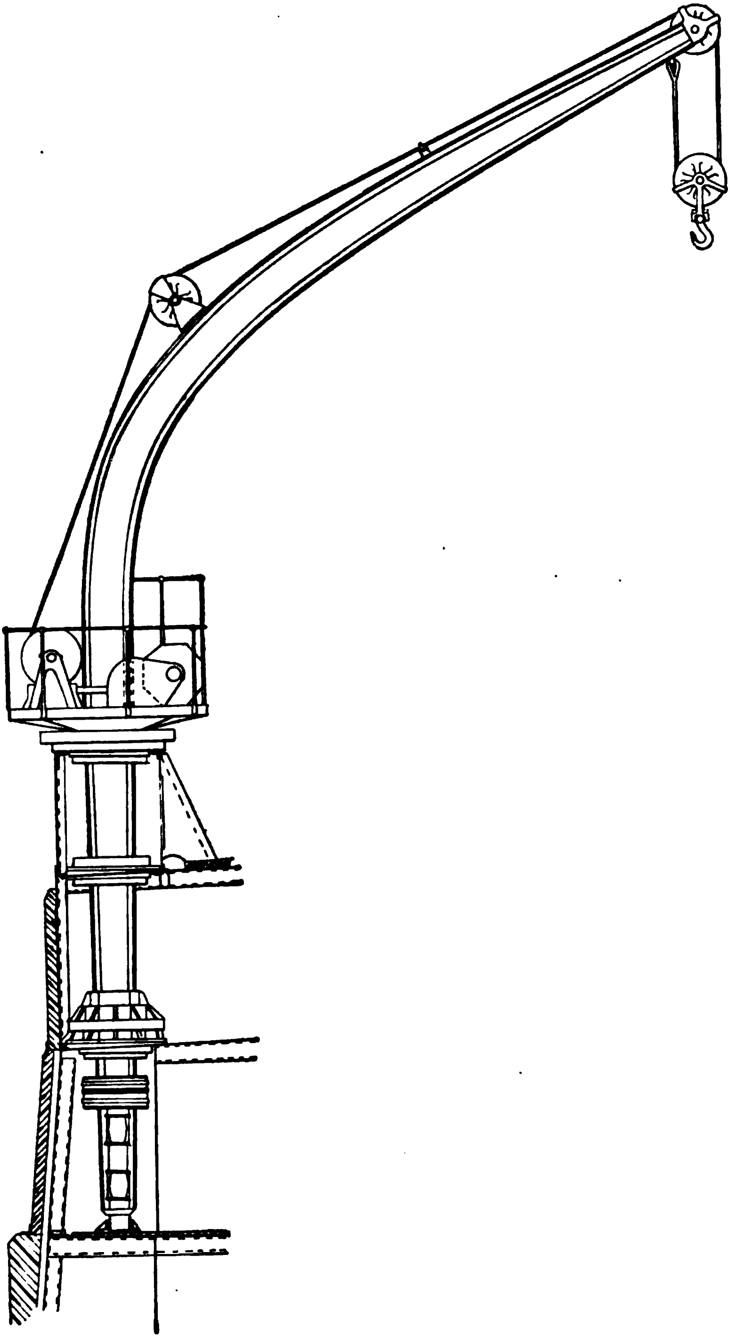


Fig. 170.—Boat Crane Built-up Davit Type.

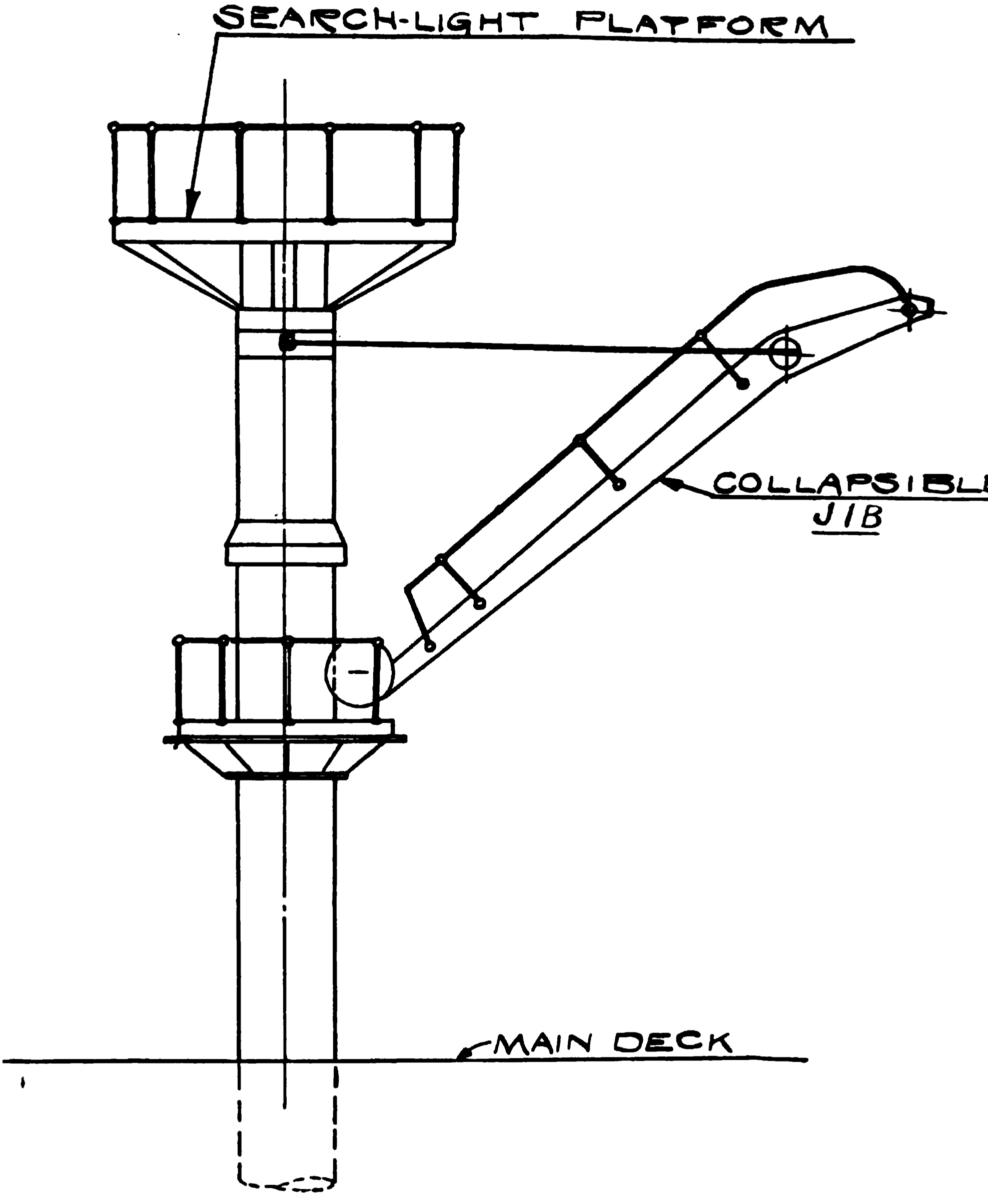


FIG. 171.—PILLAR TYPE OF BOAT CRANE.

The drainage system of a ship is for the purpose of removing at will from the interior of the ship, foreign water, *i. e.*, water not intended to be inside the ship.

The drainage system on a large man-of-war. consists of three essential parts; on smaller ships the principle involved is the same but the complication is less, due to the smaller number of compartments.

The three essential parts are known as:

(a) The main drainage system.

(b) The secondary drainage system.

(c) The scupper system.

The main drainage system.—This is so called because it is of the largest capacity, being intended as a means of ejecting considerable volumes of water which may find their way inside the ship, such as water entering from underwater damage, shot holes, etc.

This system in United States ships runs just on top of the inner bottom and is confined to the engine rooms, boiler rooms and similar large compartments, the filling of which will jeopardize the safety of the ship.

In its original form, and the form in which it appears in all our earlier ships, it consisted of a large main connected to the two main circulating pumps (furnishing water to the main condensers), and having a large valve in each compartment whose opening was just above the inner bottom and which is controlled from above the fire room or engine room floor plates and also on or above the lower protective deck. The piping of this system is of galvanized steel, usually about 15 inches in diameter, and the valves of the angle stop check type.

In the latest types of ships the main drain in the engine rooms is connected to the circulating pumps and discharges overboard through the main outboard delivery, but each boiler room has an independent electrically driven pump discharging overboard through an independent discharge. The motors driving the electric pumps are located above the lower protective deck. All these boiler room pumps are connected together so that each pump may draw from its own or any other boiler room or other important compartment, except the engine room.

A diagrammatic sketch of this arrangement is shown in *A*, Fig. 172.

This system has the advantage of permitting the watertight integrity of the subdivision to be better maintained as there is less piercing of the bulkheads, also the pump capacity is far greater than was formerly the case and the motive power of the electric pumps is so located as to be probably more available for use in the event of damage to the ship.

The secondary drainage system.—This system is the one ordinarily used in the daily life of the ship for draining the various compartments below the waterline of the accumulation of water that finds its way in for various more or less ordinary reasons.

This consists of one or more systems of piping of less diameter (about 5½ to 6 inches) than the piping of the main drain, with a suction connection to each compartment (other than fuel stowage compartments) bordering on the inner bottom, and to certain inner bottom compartments outside the reserve feed tank.

This system is ordinarily connected to the fire and bilge pumps located in the boiler and engine rooms, but in some cases special pumps, usually electrically driven, are fitted to handle certain parts of the system.

As a rule, individual compartment suctions are led to manifolds which connect to the pumps.

The spindles to drain valves for machinery compartments are operated above floor plates; all others lead up above the protective deck and are operated either from deck plates or stands on this deck.

The piping of such a system is of galvanized steel and the ends of suction pipes lead into pockets or wells recessed in the inner bottom, located at the lowest point of the compartment and fitted with strainers over the suction end. Macomb strainers are also fitted in the main line of the secondary drain.

A diagrammatic sketch of a typical secondary drainage installation on a very recent battleship is shown in *B*, Fig. 172.

Scupper system.—This is a system of natural drainage, employed for decks well above the waterline, usually only on the bridge, upper, main and second decks.

It consists essentially of a number of pipes, vertical or nearly so, having their upper ends or the ends into which the water enters, located at the lowest point of the compartment to be drained, and the lower end discharging overboard above the waterline.

The upper end of such pipes is fitted with a grating and the lower end with a flap valve to prevent the water rushing back up the scupper pipe as the ship rolls or pitches in the sea.

Such scuppers are usually of brass pipe or brass castings.

In the case of scuppers leading from weather decks, the upper or inlet end is located in the water-way or gutter-way, which is specially fitted for draining water to the scuppers.

Balancing or compensating systems.—The most recent ships have a balancing system of piping cross connecting the outboard lower compartments by means of which, if a lower wing compartment on one side of the ship is bilged or flooded, an equal amount of water is admitted to the compartment on the opposite side, thus tending to keep the ship on an even keel.

Other water systems.—Each ship, in addition to the drainage systems explained above, has certain other piping systems as follows:

Flooding.—This is a system by means of which water from the sea is admitted through sea connections to various parts of the ship, mostly magazines, for the purpose of extinguishing fires, etc.

With the modern practice of stowing most of the ammunition well above the inner bottom, it has been found necessary to flood most of the upper magazines from connections to the fire main since the head of water outside is not sufficient to flood them rapidly enough from the sea; such connections are arranged in the form of sprinkling systems in the magazines over the ammunition.

All compartments requiring to be flooded, which includes in general double bottom compartments (which are flooded through the secondary drainage system), trimming tanks, ammunition rooms, etc., require to have air escape pipes which are led from the highest point in the compartment to well above the waterline. All valves in the flooding system are controlled from locked deck plates or stands on the lower protective deck.

Fire main.—A system drawing water from the sea and forcing it by pumps through pipes to hose connections in all parts of the

ship for protection against fire. This system on most modern ships is run either below the protective deck, or between the upper and lower protective decks, with risers direct to hose plugs in the various compartments above the upper protective decks.

It was formerly made of copper piping, but is now of lead lined pipe.

A pressure of about 100 pounds per square inch is maintained in the system by the fire and bilge pumps located in the fire rooms, engine rooms and pump rooms.

Fresh water system.—A system drawing from the ship's fresh water tanks by means of special pumps, usually electric pumps, and carrying fresh water to baths, galleys, pantries, bakeries, etc.

In principle it is not different from the water systems in an ordinary building on shore and its arrangement is always special and dependent on the internal arrangement of the ship.

Salt water system.—A system similar to the fresh water system connecting with salt water showers and baths and used as flushing water for water closets and plumbing fixtures; sometimes for crews' heads special and independent systems are fitted.

Plumbing system.—Consisting of special drains and scuppers from baths, water closets, and urinals.

CHAPTER XX.

COALING.

The most recent battleships in the U. S. Navy have been designed as oil burners solely.

All destroyers since No. 21 are oil burners and recent auxiliaries are also oil burners.

Oil as a fuel presents many advantages and if the continuance of a proper supply can be assured, it seems probable that oil will continue to be the fuel for naval vessels.

There are, however, many coal-burning vessels in the navy which will continue as important fighting units for many years.

The provision for means for rapidly coaling vessels of war is a matter of great importance. In foreign services, notably the British, a transporter system has been fitted for coaling from alongside. (See Atwood's Warships.) In the U. S. Service some experimenting has been done with certain systems of coaling at sea, in which the collier is towed by the ship coaling, or vice versa, and the bags of coal transported on rope runways attached between the masts of the two vessels. The results of these experiments up to date have not been such as to justify fitting these systems generally, although two U. S. Navy colliers are fitted with these installations, and the general provisions are for coaling from colliers or lighters alongside.

The general subject of coaling is divided into three important parts:

(1) Getting coal from collier to ships.

(2) Getting coal into bunkers.

(3) Getting coal from bunkers to fire rooms ready for use in the boilers.

Owing to the watertight subdivisions of warships, and the protective decks fitted, the two latter are especially difficult.

Getting coal from collier to ships.—In the U. S. Service this has resolved itself into one of three systems so far as the warships them-

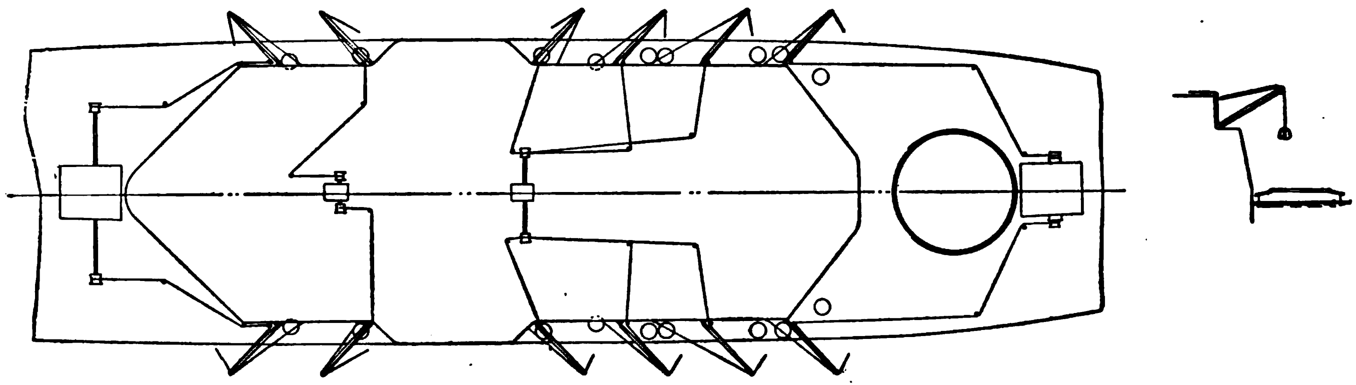


FIG. 173.—COALING WITH BOOMS.
Outline of Arrangement on Warship.

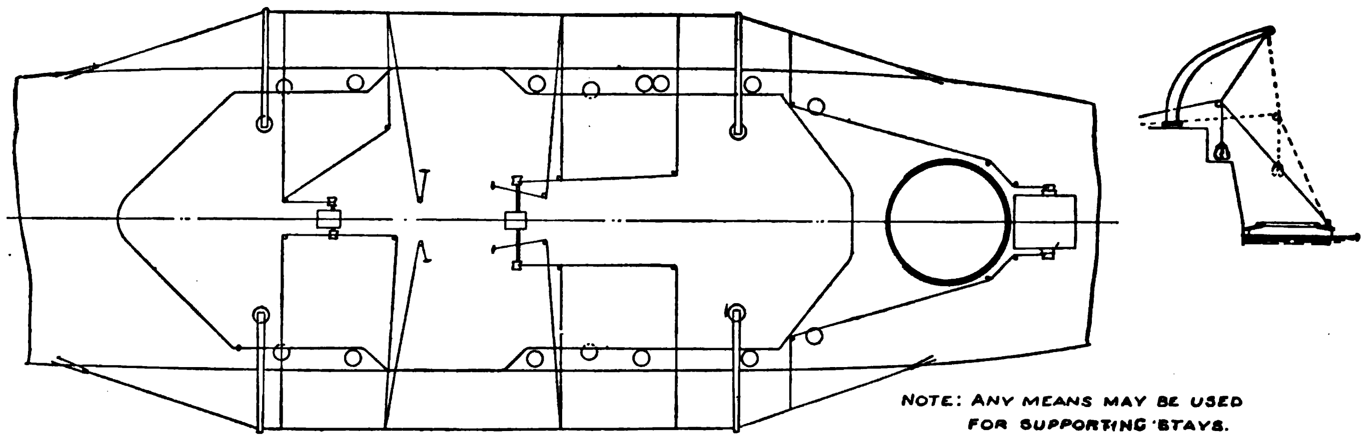


FIG. 174.—COALING WITH TRIATIC STAYS.
Outline of Arrangement on Warship.

selves are concerned: (a) By coaling booms fitted to deck of the warship so as to hoist coal bags (these bags hold about 900 pounds, and are hoisted one, two, or three at a time) and deposit them either on the upper deck, or through trunks on to some lower deck. These booms are so fitted that when swung out they project beyond the side of the ship an amount sufficient to plumb or nearly plumb the hatch of a collier or lighter, and the falls are so led that the process of hoisting also swings the boom into a position such that it plumbs the trunk on the warship referred to above, or lands the bags on the deck in a suitable location, if to be landed on the upper deck. The hoisting is done by electric winches, fitted with double drums, of which there are generally two aft, two on the superstructure, and two forward. (This arrangement is shown in Fig. 173.)

(b) By rigging a wire span from the heads of the boat cranes or other suitable outriggers on which are rove whips by which the coal can be hoisted and lowered on deck as above. (This arrangement is shown in Fig. 174.)

(c) By combination of (a) and (b).

The U. S. Navy is now provided with a number of specially designed fuel ships, some of which are fitted for carrying both oil and coal, and some only for carrying coal.

All these special naval colliers are fitted with arrangements for delivering coal directly from the collier's hold to the deck of the warship, ready to be stowed below.

This is usually done by a system of clam shell buckets which dig the coal from the collier's hold, hoist and deliver it to the warship's decks. (See Figs. 175 and 176.)

There are not enough of such colliers, however, to provide for the full needs of the fleet and as the ordinary merchant collier, such as must be pressed into service in war times, is not provided with these special arrangements, the fittings on the warship itself, referred to above, are still of importance.

Getting coal into bunkers.—The considerations determining the location of coal bunkers in warships will not permit of as large, roomy, and accessible bunkers as is the practice in the merchant service.

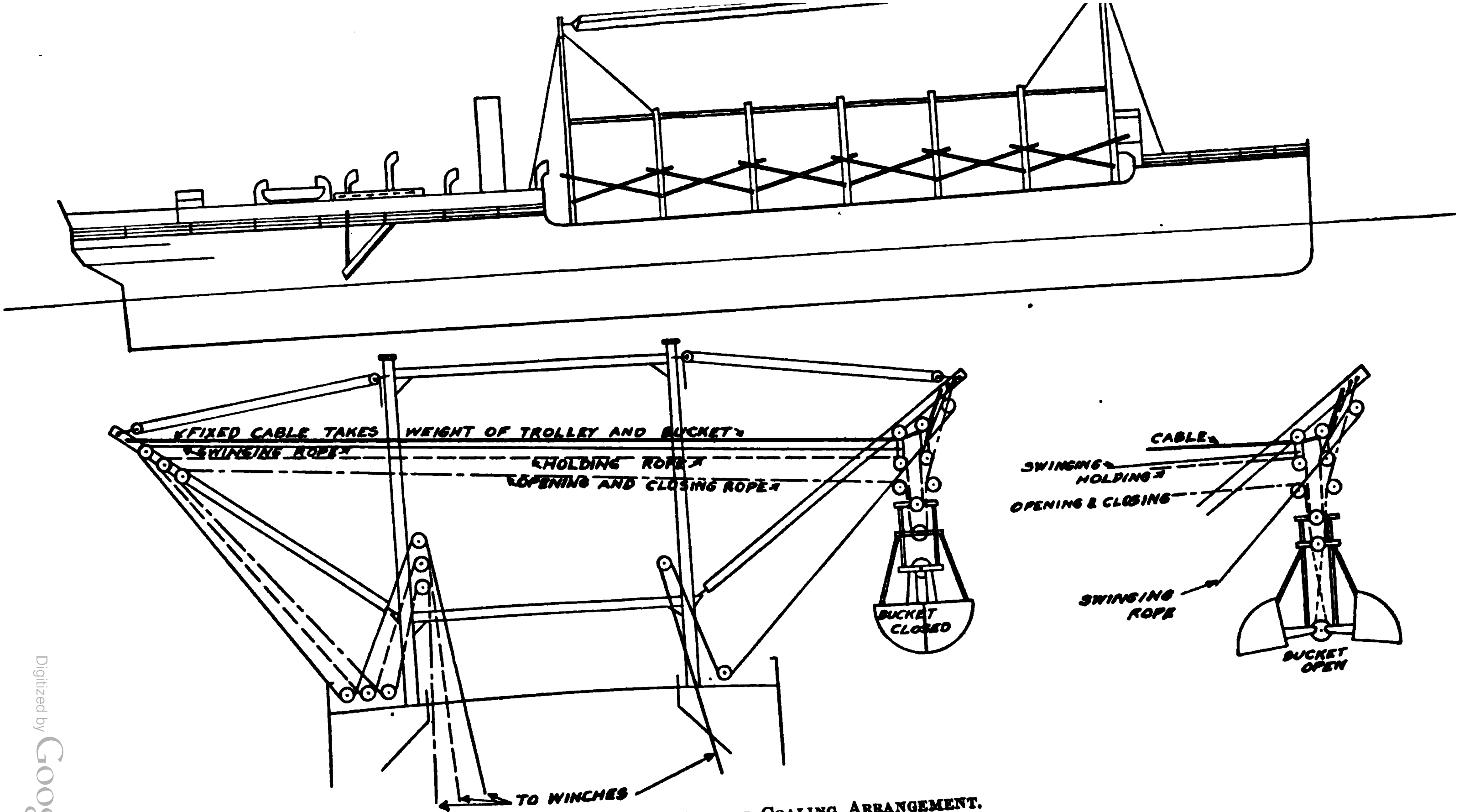


FIG. 175.—CYCLOPS COALING ARRANGEMENT.

As we have seen above, it is customary to locate the coal bunkers, part outboard of and abreast the boiler rooms, and part above the berth deck, in which location they furnish a certain amount of protection and intérfere less with the stowage of ammunition, etc., than elsewhere. In some ships it is possible to get athwartship bunkers, but in general the location is as above.

Owing to the fitting of armor and guns on the sides preventing the cutting of sideports, and other considerations, the system of coaling over all, or from the upper weather deck, has been developed. Taking a battleship of the *Connecticut* type, we find on each side, through the main deck, six openings, each from 4 feet 6 inches by 6 feet to 6 feet square, fitted with large skylight covers and about equally spaced in a longitudinal direction over the length of the coal-bunker space below. The coal is lowered to the second deck through these trunks or skylights, and there by trucks wheeled to the dumping place on either side of the ship.

From the second deck to each lower bunker lead one or more trunks 36 inches square and watertight from second to third deck. In the top of each trunk is fitted a round brass scuttle 24 inches in diameter. Where these trunks pass through the upper bunkers, a hinged watertight door 21 inches by 30 inches, hinged to swing into the trunk, is fitted to permit coal to be trimmed from upper to lower bunkers. There are fitted to each upper bunker two scuttles in the second deck. From the second deck to each fire room is led a trunk with a small trimming door, as described above, opening into the upper bunker, by means of which coal may be delivered from the upper bunker directly onto the fire-room floor.

The most recent ships have direct chutes leading from the weather decks to the coal bunkers. That part of the chute between second and main decks telescopes into a trunk through the upper bunker in the case of leads to lower bunkers and is portable and stowed away in the case of leads to bunkers between second and protective decks.

In stowing coal bunkers, it is necessary to provide means for the men stowing the coal to escape, and a small escape door is fitted in the inner longitudinal bulkhead well up under the protective deck for each of the lower bunkers, and an escape scuttle in the gun deck

Naval Construction.—To follow Page 346. Fig. 176.—U. S. S. Cyclops.

for the upper bunkers; these are fitted near bulkheads, and rungs are fitted on the bulkheads to get at them.

To permit trimming coal fore and aft within the bunker space, it is usual to fit in the athwartship bulkheads, watertight trimming doors, *i. e.,* watertight doors having small doors inside them, one door swinging one way, and the other the other way. (See Fig. 177.)

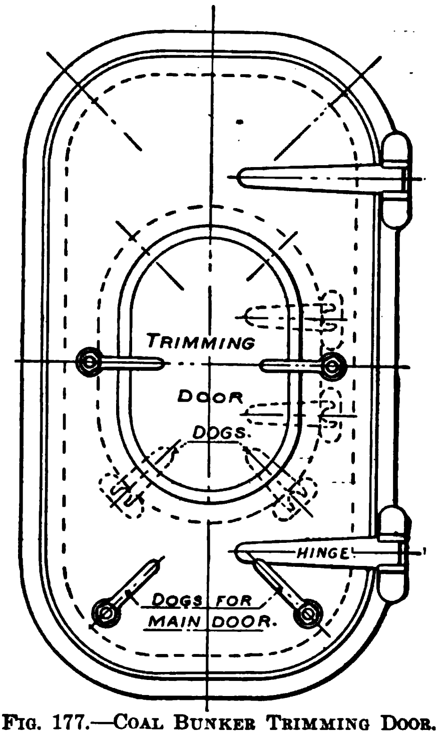


FIG. 177.—COAL BUNKER TRIMMING DOOR.

I-beam trolleys are fitted fore and aft, having hinged portable pieces in wake of these doors, and on these are run trolleys carrying coal buckets. (See Fig. 178.)

In the most recent ships these tracks are only fitted in upper bunkers, the lower bunkers having no openings in transverse bulkheads.

Getting coal from bunker to fire room.—For the lower bunkers, there is fitted to each fire room a door to each lower bunker adjacent to that room. These doors are of the vertical, sliding, watertight type, and operated by electric power or by hand.

After the coal has been used from the lower bunkers, it has to be trimmed down from the upper bunkers, and is either trimmed directly to the fire-room floors, or into the lower bunkers through

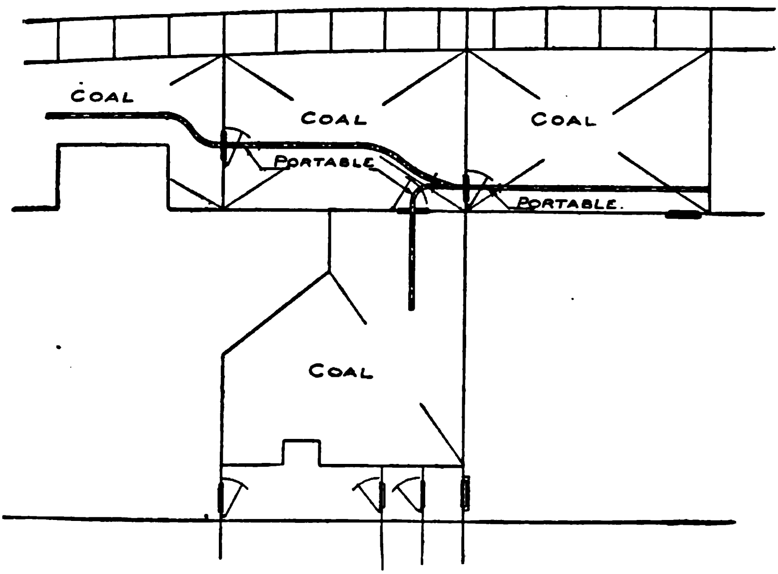


FIG. 178.—PLAN OF TROLLEY TRACKS IN COAL BUNKERS.

the trimming doors in the trunks leading to the lower bunkers, both as explained above.

Care must be taken to screen the watertight doors to prevent the coal jamming them so they cannot be opened or *closed.* These screens are as shown in Fig. 179.

Two sides support a sloping top plate, keeping the coal from the door; these are all hinged so that when the door is free from coal, the side plates may be hinged aside and the top plate hinged up out of the way.

The most recent coal-burning battleships have the bunkers above the protective deck, so arranged that the coal may be trimmed direct through chutes onto the fire-room floor plates.

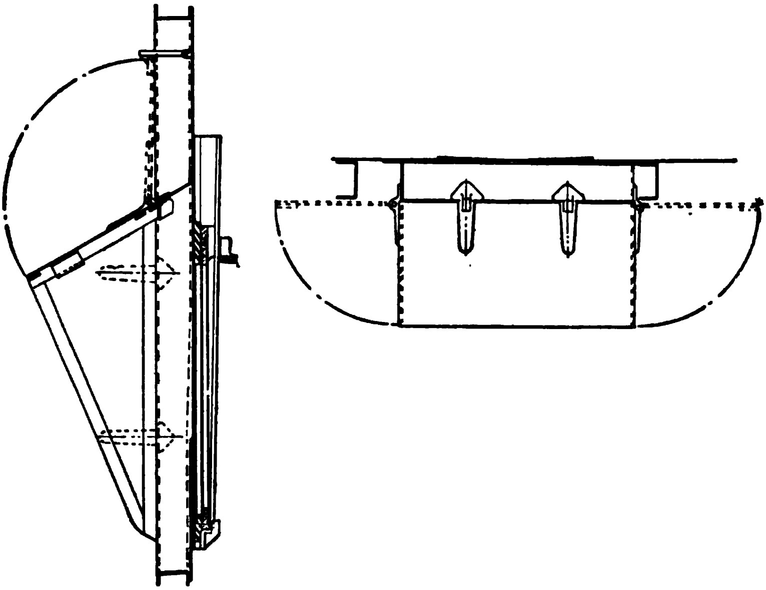


FIG. 179.—SCREEN FOR COAL BUNKER DOOR.

In addition to providing an easy means of handling the coal, this system permits the lower coal bunker doors to be kept closed in action and thus greatly adds to the protection given by the bunkers to the ship as a whole.

CHAPTER XXI.

VENTILATION.

The problem of the effective ventilation of a ship is complex and has been the subject of considerable study.

Ventilation is either natural or artificial. Natural ventilation means the supply of fresh air and exhaust of foul air without the aid of fans. Artificial ventilation means ventilation by means of fans.

From the designer's standpoint each new design presents a new set of ventilation conditions the effect of which at the best can be estimated and provided for in advance only as calculations and accumulated previous experience may guide.

In any ship certain limiting conditions obtain; in a warship these limitations are doubly stringent; for example, below watertight decks piping must not pierce watertight bulkheads, as these are vital to the safety of ships. It is undesirable to pierce armor of splinter bulkheads in any portion of a vessel, as the continuity of these is necessary for the maintenance of its military efficiency.

Holes in the protective deck for the same reason should be minimized.

Weight must be kept down in the ventilating system as in all other systems, so as not to unduly rob the military features.

The encroachment on living space and head room must be as little as possible.

The location of the source of supply of fresh air must take into consideration battle as well as cruising conditions.

The electric power taken to run the blowers must be the least possible amount in order not to increase the generator capacity or to too greatly enlarge the coal consumption.

In a design each space is preassigned to a definite use, and the requirements as regards air supply are then considered. Compartments naturally group themselves into several classes. Those that are supplied with ample ports and hatches, so that any artificial form of ventilation is not normally required, *i. e.*, spaces similar to

those in the average house on shore; those not subject to abnormally high temperatures so that provision of opportunity for natural circulation is sufficient; and those whose location or use are such as to subject them to abnormally high temperatures, and require them to have forced supply or exhaust, or both.

Beginning with the era of steamships and more definitely with those of iron or steel, ventilation has become an important feature of all vessels other than cargo ships.

With the increase in size and the numerous subdivisions of the vessels the difficulties of obtaining the proper ventilation have increased very rapidly. The watertight subdivision of the ship is of major importance in any naval vessel, and this subdivision cannot be maintained with numerous ventilation ducts leading through watertight bulkheads and decks. In all ventilation work below the waterline it is therefore necessary to limit the size and number of pipes to a minimum and to so lead these pipes as not to cut watertight members. If such cutting is unavoidable, valves must be provided to insure watertightness when needed.

Fortunately, however, the large and specially heated spaces, like engine rooms, dynamo rooms, etc., are less subject to such limitations than other parts of the ships, and for those spaces the design of the ventilation system reduces itself to the problem of providing sufficient fresh air for the men stationed there and of reducing the temperature of the compartments to livable conditions.

The method of propulsion by power introduces artificial sources of heat and causes dissemination of heat within the structure of the ship by radiation, conduction and convection, and these conditions must be provided for.

This heat is commonly known as wild heat and its amount is at best only approximately known. The wild heat liberated in any compartment can be predicted only in a comparative way, and even with two vessels of similar design the results will not be exactly alike. With different methods of insulation and lagging, and the different arrangement of compartments adjoining a live source of heat, the results will be very different. The method of insulating used on all naval vessels until recently was by ventilated air casings.

It has been found that this method, while satisfactory when rapid changes of air can be obtained, often gave unsatisfactory results owing to the numerous small branches required to distribute the air to the various pockets between beams and stiffeners, and to the fact that these branches must of necessity traverse heated compartments before reaching the air casings. This makes it impracticable to obtain the necessary changes of cool air, and in consequence some of the air casings were at a temperature as high as the compartment containing the source of heat.

It has therefore appeared desirable to provide other insulating material and to distribute it so as to prevent the transmission of heat by conduction.

Artificial ventilation is divided into two general classes: (1) *Plenum,* where fresh air is forced in and allowed to exhaust naturally; (2) *exhaust,* where bad air is drawn out and fresh air is allowed to enter naturally. The plenum system generally requires some special outlets for the exit of air, and the exhaust system some special inlets for the entrance of fresh air, though in both cases natural inlets and outlets are utilized as far as applicable.

The *exhaust* system by itself, after years of trial, has been generally abandoned in the navy, except for spaces such as water closets, etherizing spaces, etc., where bad odors must be taken out. Recently specially heated spaces, like turbine machinery rooms, closed down under a protective deck, dynamo rooms, and evaporator rooms, have air forced in mechanically and exhaust mechanically also, thus making a combination of the two systems mentioned above.

Even the *plenum* system, satisfactory as it is in most cases, sometimes fails when natural openings alone are utilized for the escape of air. In a series of compartments all connected by means of doors or hatches, ventilated with the plenum system, the air from one space, if depended on to find its way to the outside, will have a considerable effect on the compartments adjoining, through which it must pass on its way out. To avoid this and to produce the best results it is necessary to provide an independent natural exhaust from each compartment fitted with artificial ventilation. On a naval

vessel this might require considerable piercing of watertight decks and bulkheads and the practice must be limited.

Forced ventilation systems have undergone many changes in their methods of mechanical accomplishment. The first were operated by steam driven fans centrally located, supplying long systems, the pipes of which ran fore and aft and up and down, often pierced watertight members, and depended on complicated valves to maintain the watertightness of the structure.

Following these were similar systems supplied by electrically driven fans. Both these types will still be found in some of our older ships. Usually a ship had from 6 to 8 such systems, with, say, 2 fans forward, 2 or 4 amidships, and 2 aft. It came to be realized as a result of experience, that these long leads of pipe, with their complicated valves, were undesirable and that the valves were frequently undependable. From this fact rose the present method of multiple, independent, electrically operated systems.

In modern ships no system pierces a transverse watertight member unless well above the waterline. The piping is made watertight to a considerable height above the waterline, so that if one compartment is flooded the ventilation pipe will not furnish a conductor for the water to an adjoining compartment.

A modern warship of large size will have 40 to 50 such systems, each independent of the other in all respects.

The design of blowers and piping has been made the subject of careful tests, and specifications for fans and for pipe design are now issued which practically assure the attainment of desired results in the system if properly carried out. The design of blowers involves questions of pressure, velocity, and efficiency that are rather more complicated than in most machines. Piping designs include questions of shape, size, finish, angle of bends, all of major importance.

The question of measuring the air delivery has also received particular care, so that not only can the results be obtained, but also the inspector may be sure that they have been obtained.

The rates of change of air in various compartments are established with reference to use to which the compartment is to be put.

The most important things to which attention must be paid in establishing such rates, are:

(a) The number of human occupants and their occupation.

(b) The character and extent of artificial sources of heat within or adjacent to the compartment.

From the number of human occupants of a space the necessary amount of fresh air for human comfort can be approximately calculated. This calculation would be based on the amount of CO_2 exhaled by the occupants, and would aim to provide sufficient air to reduce the percentage of CO_2 to a living condition.

The composition of pure air is approximately 21 per cent oxygen, 79 per cent nitrogen, and 0.034 per cent CO_2. This is the air which enters the lungs, but on being exhaled the composition becomes 16 per cent oxygen, 79.6 per cent nitrogen, and 4.38 per cent CO_2. The oxygen therefore has decreased and the CO_2 increased. From these figures and the fact that at one breath 25 cubic inches of air are inhaled, at a rate of breathing of 18 times a minute, it may be calculated that each member of the crew shall liberate 0.7 of a cubic foot of CO_2 per hour.

It then becomes necessary to determine just what percentage of respired CO_2 may be allowed in the living quarters. While the amount of CO_2 in the atmosphere is very small, 0.034 per cent, if it should be increased to 1 per cent by the addition of chemically pure CO_2, it could be breathed without disagreeable results. But if this amount of expired CO_2 were present, the air would be unfit to live in continuously. If it is desired to maintain a percentage of respired CO_2 of 0.02 per cent (a figure established by some eminent writers on the subject) it will be necessary to provide each man with 3500 cubic feet of fresh air per hour. This amount of fresh air per person, while perhaps desirable, is seldom obtained, even in hospitals, shops, theaters, schools and other buildings.

In crew spaces on naval vessels it is usual to allow 35 cubic feet per minute (or 2100 cubic feet per hour), which, if properly distributed, would give good results, but it is, of course, impracticable to install the numerous small outlets necessary to obtain absolutely uniform distribution, and as a consequence some men may be subject to pure air with drafts and others to foul air and insufficient circu-

lation. As a result it is not uncommon for the crew to stop up the ventilation outlets, which adversely affects the general results.

The amount of air referred to above would only provide sufficient renewal for keeping the respiratory CO_2 to a comfortable working condition and does not in itself provide for carrying away the wild heat, which is a variable quantity and differs in all the compartments. Separate and usually additional allowance is made for caring for the heat in spaces especially subjected to such artificial heat.

From recent specifications the following rates of change of air in various compartments are quoted, these rates of change having been obtained from past experience in combination with a theoretical determination:

Officers' quarters and crew's space not inclosed by armor, in from 10 to 12 minutes.

Officers' quarters and crew's space inclosed by armor, in about 4 to 6 minutes.

Sick-bay quarters, in about 8 minutes.

Water-closet spaces, in about 4 minutes.

Store rooms, in from 15 to 30 minutes.

Engine and steering engine rooms, in about 2 minutes.

Steering-gear compartments, in about 8 minutes.

General workshop, in about 4 minutes.

Switch and distribution board rooms, central station, fire-control booths, and interior communication rooms, in about 6 minutes.

Refrigerating machine rooms, in about 4 minutes.

Evaporator rooms, in about 4 minutes.

Dynamo rooms, in about 4 minutes.

Windlass engine room, in about 4 minutes.

In a warship, necessary as ventilation is, it must, after suitable provision has been made for the general health of the crew, take somewhat of a secondary position with relation to the prime function of the ship—the carrying of the two military features of armament and protection.

Until very recently all naval ventilation systems were with cold air solely. The cold air has been blown in low down, with the idea that as it became heated it would rise. This has generally given rise

to the complaint of cold feet. It has been blown in high up, and in crew's hammock space complaint has been made that men sleep cold in their hammocks.

To blow in at half height means either that the duct must be led to a bulkhead, where it can be taken down to the desired height, or it will be an obstruction.

The present movable type of outlet called the McCreery elbow solves the question reasonably well and allows the duct to be kept out of the way and the air to be directed up, down, or in any other direction desired.

On the *Vermont* a test installation was made with one system in which heating and ventilation were combined. The reports received early in 1908 from the ship were so good that the system was extended.

Beginning with the *Florida* and *Utah* the heating and ventilation have been combined for the systems supplying crews' quarters, officers' and some other spaces. This combined system was not carried to store rooms nor to other places where the heat was not necessary.

The combined system permits the regulation of the temperature to a uniform degree. The piping is so arranged that the temperature may be controlled through part of its range by regulating the proportion of cold air and heated air, and through the balance of the range by regulating the heat.

From the point of view of the constructor, the combined system has the advantage of saving height and wall space by doing away with the old radiators. It prevents accumulation of dirt and is economical of fuel.

It sometimes presents difficulties in getting the steam coil box located without interference with head room or other essential features. Medical officers' reports have been generally favorable to such a system.

There is, however, one objection to this combined heating and ventilating which may apply to a greater or less extent in any system of heating, and that is the relatively low humidity which results.

It might appear that the introduction of a small amount of steam into the heated air would be the simplest remedy, but while this has

been done in certain cases, it is found to be unsatisfactory unless the steam supply is constant, automatic, and of approximately the right amount.

There are a number of machines in use in buildings on shore which automatically wash, heat, and humidify the air to any desired temperature or relative humidity, but the apparatus is heavy and complicated and takes up considerable space, and whether it would prove satisfactory on a naval vessel is still to be determined.

The magazine refrigeration system as usually installed is the converse of this combined heating and ventilating system; that is, it is a combined cooling and ventilating system. It has certain features peculiar to itself, but in essentials the systems are identical.

The question of the location of blowers is one of importance.

The longer and more circuitous the lead to the blowers, the worse from a productive standpoint. On the other hand, a blower cannot well be located in the open, and if located anywhere outside of armor will be expended early in action.

For those blowers that are in the nature of luxuries or pure comforts a location outside of armor is justifiable.

For blowers on which human life or the military efficiency of the ship depends, such as engine-room blowers and magazine blowers, the location must be the best possible.

These blowers are therefore in the latest ships not only placed behind armor, but below the protective deck, to provide, so far as possible, for their preservation in action.

The location and form of inlet cowls to blowers is also a matter that requires special attention. For systems that are to be run during action these cowls must be located, as far as possible, so as to avoid sucking in smoke or the fumes of explosive shells. They must be placed so as not to interfere with the use of turrets or smaller guns. The ventilation for turrets themselves is now either taken through the roof or through the underhanging shelf plate at the rear. Cowls located where exposed to sea or spray, must either be removable, be unusually high, or be of special form.

Various kinds of cowls of the mushroom type or special form have been tried for such purpose, but without exception it has been found

that from an efficiency point of view they are all inferior to the standard form similar to that used on merchant vessels.

In special cases, however, the lack of efficiency must be accepted and the special forms fitted.

The ventilation of the most modern warships may be illustrated by the following examples, which represent typical cases on board such ships:

Second deck and the spaces thereon.—This deck in a battleship is usually from 12 to 14 feet above the water. It is the next deck below the weather and there are plentiful air ports and gun ports in the side and companion hatches and skylights above. It is ordinarily not artificially ventilated, and so far as conditions go, requires artificial ventilation no more than a large room on shore.

Store rooms.—Store rooms are down in the depth of a ship. Air to get to them would have to follow a circuitous and unnatural route, and they are not customarily occupied by men. They are therefore usually fitted with plenum ventilation and the air is allowed to escape by the natural routes of hatches, doors, etc., provided for other purposes, and in special cases exhaust pipes are fitted.

Dynamo room.—Here we have a room with artificial sources of heat within the space. The room is, however, relatively small and high and lends itself to the exhaust trunks, which trunks have to be provided for other purposes. They are generally fitted with forced ventilation and natural exhaust through specially prepared openings. Recent experience has, however, indicated that forced exhaust ventilation, as well as forced supply, is desirable.

Engine room.—Until recently engine rooms were fitted as described under dynamo room, but with the large radiating surface of the turbine, the relatively small hatch that can be fitted and the necessity for ample protection to the main propelling mechanism of the ship, considerable hot pockets resulted, so that the most modern systems have air forced in and drawn out both by fans, the leads for both inlet and exhaust systems being taken to the various parts of the space to relieve hot pockets and to furnish air for the occupants for the room. The number of outlets, however, is reduced to the smallest number practicable and the area of each correspondingly enlarged.

Spaces such as turrets where the work is strenuous and the heat considerable also require much air.

In some turrets sufficient air is blown in to keep the turret under slight pressure to assist in expelling gun gases when the breech is opened.

It is desirable from the efficiency standpoint to have the air introduced at the highest velocity practicable, but if this velocity is too high, disagreeable whistling occurs, so that it has been found necessary to limit the velocity to 1500 feet per minute.

For living spaces it is endeavored to introduce not less than 35 cubic feet per man per minute, though when the space is so located as to provide readily for natural ventilation this is allowed for and not all the air is introduced by fans.

Experiments have been made with various forms of cinder and dust extractors, but invariably they have shown a large reduction in efficiency of the system. As the principal source of such cinders and dust is the coal burned, and as we are now changing to oil burning, this particular difficulty should decrease in importance.

Coal-bunker ventilation.—The ventilation of coal bunkers is important on account of the gas coming from certain kinds of coal. This gas, when mixed with air, forms an explosive mixture and might cause serious damage if allowed to accumulate.

The coal bunkers are ventilated by leading pipes from the coal bunkers to uptake enclosure. These enclosures are hot and the air in the pipe tends to rise and, for the lower bunkers, fresh air comes in from the boiler room. It is necessary to fit a damper in these pipes to prevent the pressure in the boiler room from being lost when steaming under forced draft.

There are differences in the fittings of different ships, but the general principles may be seen from Figs. 180 and 181.

In this ship there are two general divisions of bunkers:

Upper bunkers.—Above protective deck and behind armor.

Lower bunkers.—Below protective deck and abreast boiler and engine room.

From each upper bunker, a duct of galvanized steel tubing is fitted and led to the uptake. No valves are fitted in these pipes. For each bunker, this pipe is taken from one corner of the bunker,

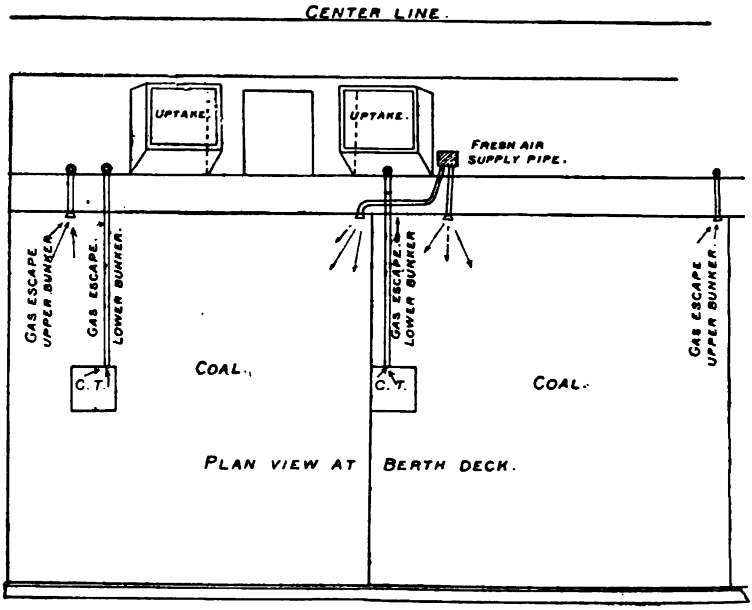


FIG. 180.

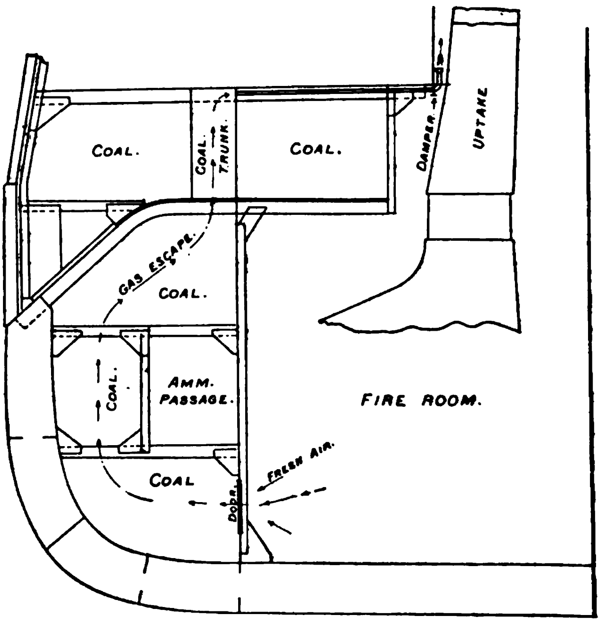


FIG. 181.

and in the opposite corner, fresh air is introduced through a similar pipe from the adjacent ship's ventilation system.

Lower bunkers.—The exhaust pipes are taken well up under second deck from the coaling trunks leading from above to the lower bunkers, and led to the uptake casing in the same manner as for upper bunker. No special supply pipe is fitted. Fresh air coming in from the doors into boiler rooms.

Double bottoms.—For confined spaces, such as inner bottoms and unfilled cofferdams, which are closed for long periods, care should be taken not to enter them without first testing to see if the air will sustain life. This is best done by trying a lighted candle in the space for a few minutes. If it will continue to burn, the air will support life.

The manholes to inner bottoms are fitted in pairs and as far apart as possible, and small portable electric blowers are used to change the air if desired.

Ordinary ship ventilation.—For ships up to and including the *Alabama* class, this was by groups of large steam-driven fans. A group was located forward, one aft, and one or two amidships, or in this general manner, usually on the upper platform deck, and from these, long ducts of considerable size were led the length of the ship, with louvres and ducts into the various compartments requiring ventilation. This system necessitated piercing many watertight bulkheads, and at these points, automatic valves were fitted to close openings when in contact with water. In the U. S. Service, only two types of these valves were ever much used: The plain ball valve, in which a hollow copper ball floated up when water came into the pipe and seated itself in a seat, forming a watertight joint (see Fig. 182), and the valve designed by the late Naval Constructor Woodward and used first on the *Kearsarge* and *Kentucky,* which, while working very satisfactorily, was complicated and expensive.

This general type of ventilation system has many objections:

(1) The large fans requiring steam engines, with long leads of steam and exhaust pipes, and consequent heating of compartments.

(2) Use of automatic valves to keep flats and bulkheads watertight—which seldom worked when needed—destroying the water-

tight integrity of the various compartments and hence endangering the safety of the ship.

Magazine refrigeration.—In the most recent ships all magazines containing powder are insulated inside with compressed cork and are ventilated with refrigerated air; the air is blown by the fan over

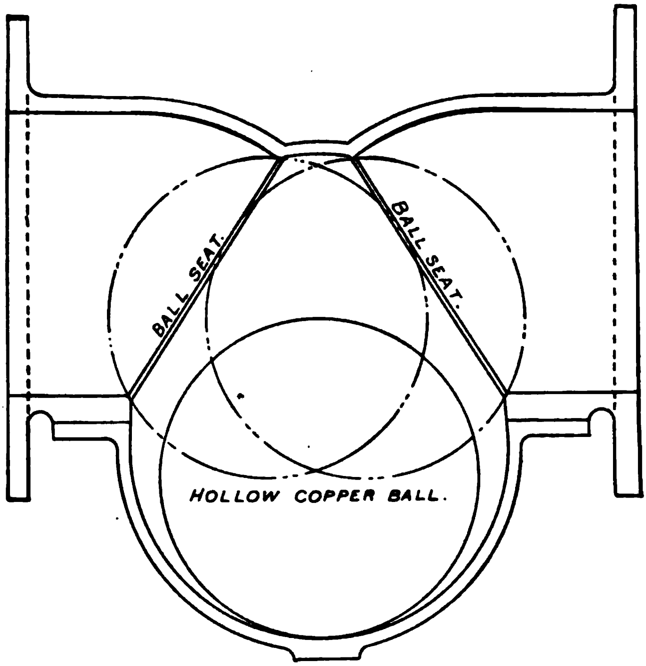


FIG. 182.—BALL AUTOMATIC VALVE.

refrigerated coils, through the magazine, and is exhausted back through the fan to be used over again on the closed circuit system.

Other systems of magazine refrigeration are used in some cases as the development of this problem is still under way. The temperature is controlled by automatic thermostats.

All ducts passing through magazines are watertight. A natural exhaust duct is fitted in each magazine not refrigerated, equal in area to the area of the supply duct, and as far removed from it as

possible. This is necessary, as magazines are ordinarily closed air-tight, and the ventilation could not continue unless some such provision were made. The upper ends of these exhaust ducts are carried well up under the second deck, fitted with a goose-neck and covered with wire mesh; the lower ends are bell-mouthed.

Special systems are fitted for ventilating engine rooms and dynamo rooms, being so led as to supply air to the specially hot parts of these rooms and to exhaust hot air, thus insuring circulation.

References to ship ventilation are not many. One may refer to an article by Naval Constructor D. W. Taylor, U. S. N., in the Transactions of the Society of Naval Architects and Marine Engineers, 1905; to Specifications of U. S. Ships, especially General Specifications for Building Ships of U. S. Navy, Edition 1912; and to various articles in the Bulletin of the Bureau of Medicine and Surgery.

CHAPTER XXII.

CORROSION, FOULING, AND PAINTING.

Rust.—If iron or steel be exposed unprotected in moist air containing carbon dioxide (CO_2), a chemical action takes place, resulting in the generation of an oxide of iron, called *rust*. This process wears away the iron.

Owing to the CO_2 present in the water, a similar action goes on for iron immersed in water.

The rusting action is much hastened by heat, and where heat and moisture are together, is very rapid.

Corrosion.—Corrosion is much accelerated by galvanic action. Iron and copper in metallic connection, immersed in dilute acid, cause an electric current, and the iron wastes away. Iron and zinc similarly immersed result in the wasting of the zinc.

Sea water is mildly acid, hence the care required in immersing two different metals in metallic connection, to be sure that they are such that the steel of the hull will not be affected.

Iron and its rust so immersed cause the electrolytic action, resulting in the wasting of the iron, from which it is evident that care must be exercised in cleaning the iron.

Rust is hygroscopic, *i. e.,* it takes up moisture, and so dampness gets between it and the iron and hastens the corrosive action.

We have seen, before, the action of mill scale or black oxide formed during manufacture, and the steps taken to remove it prior to working the plates or shapes into the vessel. Mild steel now used in shipbuilding is even more liable to corrosion than iron. A part of the thickness given the members of a ship's structure, particularly in merchant practice, is as margin against corrosion. In warships this is less true, and in such vessels as destroyers, etc., practically no margin against corrosion is allowed, and the greatest care and most frequent examinations are necessary to guard against corrosion. We have seen that the torpedo-boat plating is galvanized as an additional precaution against corrosion.

From the above it is clear that no part of the structure of a ship may be left bare, but that all must be securely protected against rust and corrosion.

Steel and iron, before applying paint, should be thoroughly dry and clean, as if not dry, the paint will not adhere, and if not clean, corrosion will continue under the paint.

The following clauses are quoted from the "General Instructions for Painting and Cementing Vessels of the U. S. Navy" (Edition 1912), a publication issued by the Navy Department, Bureau of Construction and Repair, which defines the character and manner of application of paints on board U. S. naval vessels.

This publication is furnished to all naval vessels for their guidance in painting while in commission.

Mixture of paints.—The mixture for the several colors used for ship's structure, fittings, piping, etc., shall in general conform to the formulas herein. During the building of contract-built vessels and before delivery to the government, the bureau will permit the use of paints, of proper color, mixed in accordance with contractor's private formulas, provided same have been demonstrated to be equal to the mixtures stated herein and have received the approval of the superintending constructor. If not issued ready mixed, paint used by the ship's force should be mixed according to the formulas herein. All ready mixed paints, manufactured at navy yards and issued to ships, must be *thoroughly stirred* in cans or drums before using, in order to insure that paint has proper body and to prevent waste by residue left in drums. The surplus of such paints intended for future use should be carefully protected from the air.

Cleaning metal surfaces.—(a) All steel and iron work which is to be painted or cemented shall be carefully and thoroughly scraped, scaled and cleaned down to bare surface and shall be thoroughly dry before the paint, cement, or bituminous compositions are applied. In no case shall paint or other coatings be applied over damp, oily or greasy surfaces, or over any foreign substances. Each coat of paint shall be allowed to dry hard before applying another coat, and shall adhere firmly and uniformly to the surface of the metal. Before painting galvanized work, the surface thereof shall be cleaned with an ammonia, vinegar, or other approved solution in order to

secure firm adherence of paint. *Care shall be taken not to paint surfaces which are to be cemented.* All hull steel which is not

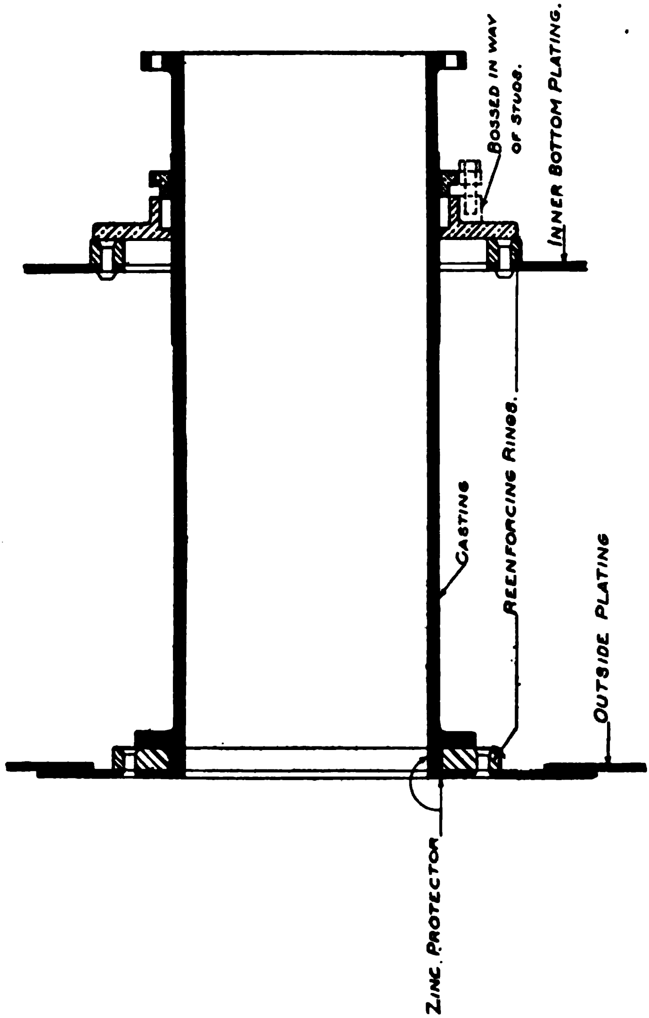


FIG. 183.—OUTBOARD DELIVERY.

pickled or furnaced shall be allowed to stand after receipt at the yard a sufficient length of time to permit of removal of the mill scale, as far as practicable, by wire brushes, before any paint is applied.

(b) The preparation of the painted surface of metal work for repainting by ship's force shall be accomplished by scrubbing it with common brown soap or soapine and fresh water, using burlap or scrubbing brushes. Where the old paint is lumpy or thick, fine sand may be used with the soap, but under no circumstances shall steel brushes or scrapers be used unless the whole surface is to be cleaned.

In the U. S. Service, the entire hull, both inside and out, is required to be painted with two or more coats of red lead, on top of which is applied the color paints as required, with two or more coats; slate color for all of outside above the waterline in the case of squadron ships and white to main deck line, with spar-colored upper works for ships acting singly in warm climates, and white or other colors inside, except for coal bunkers. The coating of all steel, therefore, is with four coats of paint.

Whenever any fitting of brass or other copper alloy is attached to or adjacent to the steel structure under water, an electric current, such as referred to above, is set up if the paint comes off, and under these conditions, very rapid pitting would take place here. To prevent this, wherever this contact necessarily obtains, strips of zinc are secured to the plating. The current set up then tends to waste away the zinc instead of steel. These zincs should always be left unpainted, and should at every docking be examined, and, if necessary, renewed. (See Fig. 183.)

Fouling.—It is necessary in considering the outside plating below the waterline, in addition to providing against corrosion, to provide against the attachment of animals and marine growths. This attachment is termed fouling, and when fouling occurs, the increase of resistance is so great as to seriously decrease the speed, or increase the horse-power and fuel consumption to maintain the same speed.

Copper is probably the most efficient anti-fouler, as, under the action of sea water, certain salts are formed which wash off, carrying with them any growth which has become attached. This action is called exfoliation.

When wooden ships were built, copper was, of later years, always fitted, but with the introduction of iron and steel vessels, this is not practicable, so that sheathed ships, such as the *Denver,* have to be built, or composite ships on which copper can be fastened, or for

ordinary steel ships, dependence put on anti-fouling compositions, to which reference has been made.

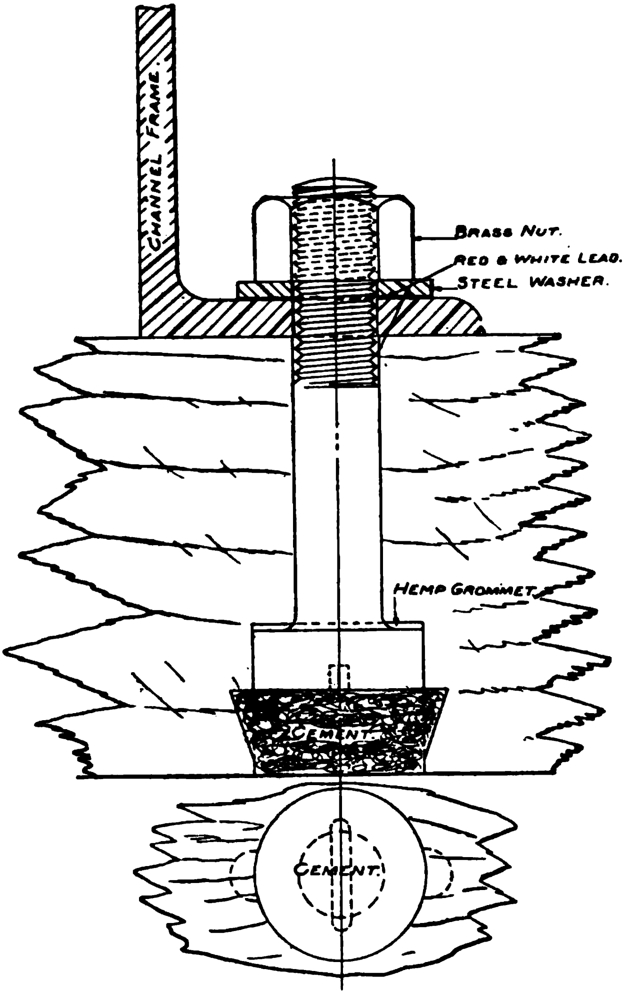


FIG. 184.

Composite construction.—*Dubuque:* In this class, as will be seen from Chapter XIII, the outside plating below waterline is limited to the flat keel, garboards, and plating in wake of hull fittings.

These vessels are planked in one thickness, 4 inches thick, the plank secured to the frames by $\frac{7}{8}$-inch naval brass bolts, the hole over the head of the bolt filled with Portland cement, and the whole outside surface of plank below waterline covered with copper from 24 to 28 ounces. (See Fig. 184.)

This type of construction is not structurally very strong and is only applicable to small craft, such as the *Dubuque.*

For larger ships for foreign service, where docking facilities are not available, the ship is constructed in the usual manner, with shell complete, of steel, and on top of this is fastened wood sheathing. This is the system of construction employed in the *Denver* class. By this means we get a ship with the structural strength of a steel ship, and with the advantage of copper sheathing.

It is essential that there should be insulation between the copper and the steel skin. In foreign services it was formerly the practice to fit the wood sheathing in two thicknesses, but this has since been abandoned in foreign services in favor of sheathing in one thickness, which is the method that has always been adopted in the U. S. Service.

The general features of this sheathing are as follows:

(1) The planking is in one thickness, 4 inches thick finished, reduced to $3\frac{1}{2}$ inches at ends. The butts of this planking are shifted with not less than two passing strakes.

(2) The plank is fastened with $\frac{3}{4}$-inch naval brass bolts, screwed through the plating between the frames, and fitted with brass nuts, the heads of these bolts being recessed in the plank as in the case of deck bolts. Hemp grommets are soaked in red lead and fitted under heads of bolts. Similar hemp grommets are fitted over the points, a steel washer put on top, and the brass nut fitted.

(3) All shell plating is thoroughly tested for watertightness before the planking is worked.

(4) All fitting, fairing, and fastening of planks is carefully done. The faying surfaces are coated with suitable compositions before fitting plank, and after planks are fitted, red lead putty is injected behind planks to fill any spaces that may have been left. The recess for bolt head is filled with cement to prevent the copper sheathing nails coming into contact with bolts and destroying insulation.

Fig. 185 shows method of fastening above described.

Sheathed vessels require the use of bronze stems, sternposts, etc., to prevent galvanic action. Manganese bronze is generally used in the U. S. Service for this purpose, giving most suitable results as to strength, etc.

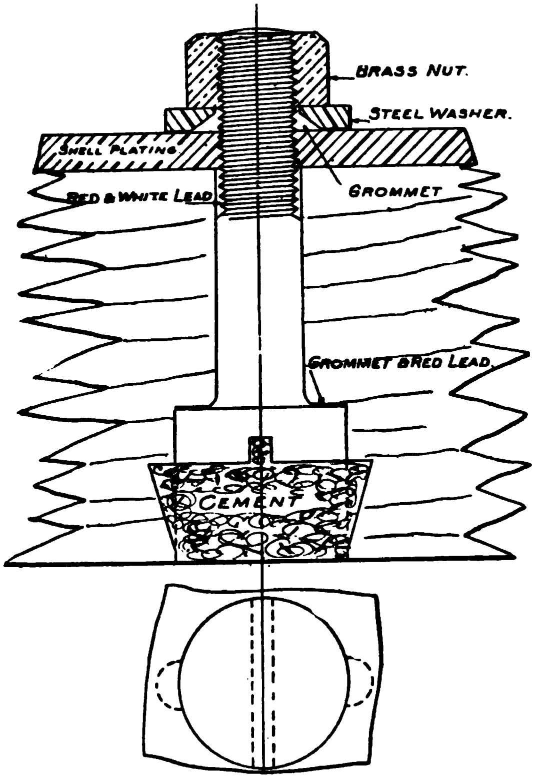


FIG. 185.

The surface of plank is payed with pitch, covered with tar paper, and then with copper sheets which are fastened with composition nails about 1¼ inch long.

In the U. S. Service, the *Denver* class is the only class of sheathed ships we have. There are several examples of composite ships, and specifications were prepared and contracts let for a class of sheathed

battleships and of sheathed armored cruisers, which, however, were later changed to unsheathed ships, as a careful consideration of the question led to the belief that the additional cost and decreased speed entailed by fitting sheathing on vessels of this class for the purposes of the U. S. Service, were more than were justified by the advantages gained.

For unsheathed ships it is necessary to rely on anti-fouling compositions to prevent fouling; of these there are many. At each navy yard in the United States there is a paint board constituted by authority of the Navy Department, who carefully examine and report on the conditions of the bottom of every vessel at the time of docking. This report, together with the length of time the vessel has remained out of dock, and her itinerary prior to docking, and probable location and service after docking, determines the recommendation of the board as to the kind of composition most suitable for any particular vessel and service.

The usual basis of these anti-fouling compositions is either copper, which, in a soapy form, acts much as does sheet copper, and in exfoliating throws off the marine growth, or arsenic, or mercury, or other poisonous matter which kills the growth.

An iron or steel ship, not sheathed, requires frequent docking and renewal of the anti-fouling composition, as its efficiency as a preventive of fouling soon wears away. In the U. S. Service it is customary to dock at intervals of not more than a year, and generally about every six months.

Prevention of corrosion inside.—We have seen above that no part of the steel structure of a ship may be left bare without serious corrosion and rusting taking place. Examination of the paint work is continually necessary to see if it is properly protecting the steel. This is particularly true of inner bottoms, boiler foundations, and interiors of coal bunkers, when they can be gotten at. Where, on examination, rust is found, or paint abraded, new paint should be applied after suitable cleaning.

Access is provided to each compartment of a ship either by doors or manholes.

As we have seen in Chapter XVI each compartment is numbered, and there is furnished to each ship a small booklet plan on which is indicated the means of access to the various compartments.

It is a natural tendency to apply frequent coats of paint. This practice when carried out to extremes, as it sometimes is, is bad and before applying new paint, surfaces should be rubbed down and cleaned to insure proper results and to prevent too great an accumulation of paint.

The following quotation from the U. S. Naval Instructions indicates the course prescribed for examining the hulls of vessels:

(1) The captain of every iron and steel ship shall appoint a permanent board of three line officers, one of whom shall be an engineer officer of the ship, for the purpose of examining and reporting upon her condition, especially as regards deterioration of the inner bottom and vertical bulkheads of boiler compartments, corrosion at the waterline, and of the underwater exterior of the ship, including valves, propeller, rudder, and all other fittings each time they are accessible. They shall also examine and report upon all parts of the top side, inner hull, and double bottoms, at some time during the quarter; the interval between two successive inspections to be not more than four months. The board shall also report upon the efficiency of all steam and hand pumps within the ship, requiring them to be tested, both for draining the bilges and for fire purposes.

(2) Where practicable, the officers composing this board shall be other than those designated in Article 1 2701 (2), but they shall be assisted by such other persons as may be necessary for the efficient performance of their duties. The reports of the board shall be forwarded to the Department (Division of Inspections).

Every such report shall include a brief statement of: (a) The general location of the ship during the period covered by the report; (b) any unfavorable conditions existing in any of the localities visited during the period covered by the report; (c) any special precautions that may have been taken for the preservation of the hull while in unfavorable localities.

(3) The report by the permanent board shall include a statement as to the structural condition of all valves and ports in the underwater outer hull, the rudders, propellers, shaft struts and tubes, torpedo tubes, bilge keels, and other fittings; also the date of last cleaning and painting, the condition of the paint at the time, and the kind of paint or composition used in repainting.

(4) The captain shall cause a hull book to be kept, in which shall be entered by the officers making them, reports duly signed, required by this article and articles I-2702, I-2703, I-2704, and I-2705 (2).

(5) For yard or station tugs, waterboats, and coal barges, the commandant shall detail an officer to make the inspections and reports herein required.

See also Articles 2702, 2703, 2704, and 2705, U. S. Naval Instructions.

At suitable intervals, when ordered, complete surveys are made by the naval constructors at navy yards.

Pipes in lower part of ship are always of galvanized iron or steel so that galvanic action may not result from bilge water or drainage water.

Cement.—Cementing, with Portland cement, in the U. S. Service, is confined to plate laps in outer shell, inside of ship, and elsewhere as necessary, to permit free flow of water to bilge wells, and is always kept as small as possible.

Cement requires careful examination and renewal if cracked as, if water gets behind it, corrosion may go on unnoticed.

Where the cement, to provide proper flow of water to drain suctions, becomes of any thickness, it is mixed with coke to reduce weight.

In applying cement, it must be applied over clean, bare metal, as rust or paint will prevent adherence.

The inner surfaces of reserve feed tanks, trimming tanks, and fresh-water tanks are covered with cement wash.

The insides of oil stowage tanks are not painted, as the fuel oil itself protects the plating against corrosion sufficiently.

In living spaces, where one surface of steel is exposed to chilling, sweating is apt to occur, owing to condensation of moisture in air. Such surfaces are cork-painted, a coat of under cork being applied over the red lead, the ground cork being thrown on while the paint is wet, and the white finishing paint applied on top.

REFERENCES.

Standard Instructions for Painting Naval Vessels, issued by the Bureau of Construction and Repair.

Iron Corrosion, Andes.

Rustless Coatings, Wood.

Corrosion-Fouling and Their Prevention, Newman.

APPENDIX A

SHIPBUILDING TERMS NOT COVERED IN TEXT OF BOOK.

1. AFTER BODY.—That part of a ship's hull abaft the midship-section or dead flat, or in case where a ship has a parallel middle body, that part abaft the after end of the middle body.

2. AFTER PEAK.—The extreme after compartment in a ship's hold.

3. AIR DUCTS.—A system of pipes for ventilation, made of light material, through which, by means of blowers, fresh air is forced into, or impure air is extracted from, the various compartments and rooms of a ship.

4. AIR PLUGS.—Small screw plugs fitted in watertight manhole and scuttle covers, which are removed when it is desired to fill the compartment with water, so that the air can escape, and are replaced when the operation is completed.

5. AIR PORTS.—Openings in the side of a vessel to admit light and air to the covered decks, state-rooms, etc., fitted to close with a thick glass set in a hinged composition frame and secured by thumb screws. A solid composition shutter is provided to close the opening in case of accident, etc.

6. AMIDSHIPS.—The middle of the ship, either with regard to her length or breadth.

7. ANCHOR BED.—A sloping recess in the upper deck on each side of the bow for the storage of the bower anchors out of the line of the fire of the guns. Short beams, for the anchor to rest and slide on are secured to the anchor beds, both the beds and the beams extending a little over the bow, so as to throw the anchor clear of the side.

8. ANGLE BAR, WATERWAY. See "Waterway Angle Bar."

9 ANGLE BOX. See "Box Angle."

10. ANGLE BULB.—An angle bar having a bulb on the edge of one of the flanges for the purpose of strengthening it.

11 ANGLE CLIPS.—Short pieces of angle iron used for connecting floor or bracket plates to vertical keel or longitudinals, etc., and for similar purposes.

12. ANGLE, DOUBLE STAPLE.—See "Double Staple Angle."

13 ANGLE, STAPLE.—See "Staple Angle."

14. ANNEALING STEEL.—The process of heating the material in a furnace and afterwards allowing the fire to die out, thus permitting the steel to cool gradually whilst remaining in the furnace. It relieves the material from any previous condition of strain and so restores its strength.

15. ARMOR BARS.—Bars placed in such hatches or other openings of the protective or armored deck as cannot be closed in action, to keep out shot and shell.

16. ARMOR GRATING.—A grating formed of heavy metal bars, placed in such hatches or other openings of a protective or armored deck, as cannot be closed in action, to keep out shot and shell.

17. ARMOR SHELF.—A wide continuous horizontal plate or longitudinal below the waterline, serving as a foundation for the vertical armor belt and the backing and framing behind the armor. Its outer edge has a watertight connection with the shell plating by means of a fore and aft angle bar.

18. ARMOR, DIAGONAL.—A protection of heavy steel plates in ships which have only a partial vertical armor belt. It derives its distinctive name from the fact, that, although a continuation of the vertical side armor, its course is deflected towards the middle line of the ship at an angle of about 45 degrees with the latter, so that both sides meet at the middle line. Its depth is the same as the vertical side armor, but in thickness it is generally a trifle less.

19. ARMOR, PLATING BEHIND.—The plating behind armor, to which the wood backing is secured.

20. ARMOR, VERTICAL.—A belt of heavy steel plates as a protection against gun attack, extending partially or entirely around the ship, resting with its lower edge on the armor shelf below the waterline and reaching to varying heights above the same.

21. ARMOR DECK.—An iron or steel deck, sufficiently thick to withstand the oblique impact of large projectiles up to considerable angles.

22. ATHWARTSHIPS.—The position of anything when placed at right angles to the fore and aft line of the keel.

23. AUTOMATIC FLOAT VALVE.—A self-acting or automatic valve fitted where watertight bulkheads and platforms are pierced for ventilating purposes, in order to prevent water passing from a damaged compartment into adjacent ones.

24. BACKING BOLTS.—Bolts with which the wood backing behind the armor is fastened to the double plating behind the armor.

25. BACKING, WOOD.—A layer of wood between the skin plating and the armor, for the purpose of distributing any blow given to the armor over a large area, so that local injury to the framing may be lessened.

26. BAR KEEL.—An external keel composed of heavy iron or steel bars of rectangular cross-section.

27. BATTENS, MOULD LOFT.—Long flexible strips of wood of rectangular or square section, for drawing in the ship's lines on the mould loft floor. For long easy lines, such as sheer lines, etc., those of rectangular section, ranging from ½″ x 2″ to ¾″ x 3″ are used flat ways, while for greater curves, such as the frames, those of square section, varying from ½″ x ½″ to 1″ x 1″ are used.

28. BATTLE HATCH.—A heavy, solid metal cover, of same thickness as the deck, for closing a hatch in a protective or armored deck, when preparing for action.

29. BATTLE SHUTTERS.—Solid metal covers placed over deck lights, etc., when preparing for action.

30. BEAMS, DECK.—Pieces of timber or rolled iron or steel shapes, for the purpose of holding the vessel's sides to their proper shape, and for the support of the deck.

31. BEAM, CAMBER OF.—Same as "Crown of Beam."

32. BEAM, CROWN OF.—The convex deviation of a beam from a straight line. The form, which is a segment of a circle, is adopted so that any water shipped on deck will readily flow off towards the scuppers and freeing ports.

33. BEAM, ROUND UP OF.—Same as "Crown of Beam."

34. BEAM, SPRING OF.—Same as "Crown of Beam."

35. BEAMS, HALF.—Beams used in the wake of hatches; they are less than half the length of full beams and run from the side of ship to the hatch carling only.

36. BEAM ARMS.—The split ends of deck beams, having the lower half of the split end bent downwards and a piece welded in, so as to afford a better means of securing them to the frames.

37. BEAM KNEES.—Same as "Beam Arms."

38. BENDING SLAB.—It is composed of a number of square blocks of cast iron fitted side by side, their united surfaces being of sufficient area for receiving the full length of any bar, etc., to be bent. Numerous holes are provided in the blocks for receiving the dogs and other tools employed in bending the bars, etc.

39. BEVEL.—An instrument composed of a stock and a movable tongue, for applying the bevellings to frames and other parts of ship.

40. BEVELLINGS.—The angles formed by two surfaces of different directions, such as formed by the transverse and faying flange of a frame angle iron. When the angle is obtuse the bevelling is called "standing"; when acute, it is called "under."

41. BEVELLING BOARD.—A narrow, parallel edge board, on which the bevels for the frames are marked.

42. BILGE.—The quickly curved part of a ship's hull between the nearly straight and vertical side and the more or less flat part of the bottom.

43. BILGE KEEL.—An external projecting fin, securely fastened to each bilge for about one-third to one-half of the ship's length. Its object is to check the ship's rolling.

44. BILGE KEELSONS.—The keelsons fitted at the lower turn of the bilge on each side, on the inside of the ship.

45. BILGE STRAKES.—The strakes of plating of a ship's bottom at the curvature of the bilge.

46. BILGE STRINGERS.—Keelson-like longitudinal arrangements fitted on the inside of the frames at the upper turn of the bilge.

47. BODY POST.—The same as sternpost; the use of the term signifies that the ship has also a rudder post, consequently it applies to single screw steamers only.

48. BOLTS, BACKING.—See "Backing Bolts."

49. BOSS PLATE.—The aftermost plate on each side of the stern tube in single screw ships. It is the last plate riveted in place and therefore arranged so that the edges are equally above and below the tube.

50. BOTTOM, DOUBLE.—See "Double Bottom."

51. BOTTOM, INNER.—See "Inner Bottom."

52. BOTTOM, OUTER.—See "Outer Bottom."

53. BOTTOM, WATER.—See "Water Bottom."

54. BOW.—The forward extremity of a ship above the waterline.

55. BOX ANGLE.—A continuous angle iron fitted around the edge of a solid floor plate and having the two ends welded together, used to connect the edges of the floor-plate to the outer and inner bottom plating and the ends to the adjoining longitudinals.

56. BRACKET FRAME.—A ship's frame in which the frame angle bar, the reverse bar and the longitudinals are connected by bracket plates, leaving a portion of the frame angle bar and reverse bar, midway between two longitudinals, unconnected.

57. BRACKET PLATES.—Plates forming a part of a Bracket Frame. They serve as a connection between the main and reverse frame angles and longitudinals, one edge being riveted to the moulding flanges of the main and reverse angle bars respectively, while another edge connects to a longitudinal, either by flange or angle clip.

58. BREASTHOOKS.—The ordinary "breasthook" is fitted at the extremities of bilge keelsons, side stringers, etc., and consists of a plate riveted to the keelson or stringer on each side, thus joining the two sides of the ship together. In the case of ordinary deck stringers the junction of the extremities of the plates on each side forms a breasthook. When fitted at the stern they are termed "crutches," however, the generic name "breasthook" is generally applied to all of them.

59. BRIDGE.—An elevated platform extending across from one side of the vessel to the other, used for purposes of observation, conning, etc.

60. BULKHEADS.—Transverse or longitudinal partitions which separate one part of the ship from another.

61. BULKHEAD ANGLE IRONS.—The angle irons connecting the bulkheads to the inner or outer shell plating or decks.

62. BULWARK PLATING.—The light plating around the upper deck to provide for the safety and comfort of the crew. It is a continuation of the hull plating, the lower edge being secured to the upper edge of the sheer strake.

63. BULWARK STAYS.—Supports for the bulwark plating. They are made of round iron, the heel being secured to the waterway angle bar, while the upper end is bent inboard for the support of the rail. About midway they are provided with a horizontal arm, called a "spur," the end of which is formed into a palm, so as to distribute the support as much as possible over the whole plate.

64. BUTT.—The end of a plate or bar. Also the joint made by the ends of two adjoining plates or bars.

65. BUTT PLATE.—A short piece of plate reaching from frame to frame in composite ships, placed under the butts of two planks of the same strake, so as to stiffen the butt.

66. BUTTOCKS.—The extreme part of the after body above the water-line.

67. BUTT STRAP.—A strap connecting the butts or ends of two adjoining plates or angle bars, etc. For plates they are called butt straps, while in the case of angle bars they are generally called angle straps.

68. BUTT STRAP, DOUBLE RIVETED.—See "Double Riveted Butt Strap."

69. BUTT STRAP, SINGLE RIVETED.—See "Single Riveted Butt Strap."

70. BUTT STRAP, TREBLE RIVETED.—See "Treble Riveted Butt Strap."

71. CAMBER OF BEAM.—Same as "Crown of Beam."

72. CANT BODY.—The cant body comprises those frames forward and abaft the square body whose planes are not at right angles to the center line of the ship.

73. CANT FRAME.—A frame *not* standing normal to the longitudinal vertical middle plane, but canted so as to be nearly normal to the outer plating. In metal ships they are only used to form the stern.

74. CARLING.—Parts of the deck framing running in a fore and aft direction, having their ends connected to the deck beams.

75 CASING.—An enclosure around hatches extending from deck to deck, as fitted around boiler and engine room hatches.

76. CAULKING.—The process of closing a seam or joint so as to make it watertight.

77. CEILING (CLOSED).—The solid wood covering on the top of the floor, extending to the heads of the floor plates to prevent cargo from getting between the frames. It has no structural importance. As much as possible of the ceiling should be portable, in order to afford ready access to the limbers, etc.

78. CEILING (OPEN).—The same as "Sparring."

79. CEMENTING.—The inner surfaces of the bottom plating are coated with cement to prevent the mechanical wearing away of the rivet heads and plating through the constant wash of the bilge water. The cement is thickest at the keel, extending up to the drainage or limber holes cut in the frames, and the rivet heads in all cases must be well covered.

80. CENTRAL SUPERSTRUCTURE.—See "Superstructure, Central."

81. CHAIN RIVETING.—See "Riveting, Chain."

82. Clip, Angle.—See "Angle Clip."

83. Coaling Scuttle.—A scuttle through which coal is put into the bunkers.

84. Coamings.—The parts of the hatchway framing which lie in a fore and aft direction.

85. Cofferdams.—Cellular subdivision around the hatches and sometimes around the ship's edges, from a little below to somewhat above the waterline.

86. Collision Bulkhead.—A watertight bulkhead, a short distance abaft the stem, to prevent water from entering the main body of ship, and to confine the damage to the part between it and the stem only, in case of collision bow on.

87. Companion Hatch.—A hatch used principally for the passage of the ship's people.

88. Composite Ships.—Ships built of iron or steel with the exception of their bottoms, which are of wood.

89. Conning Tower.—A small circular or oval *armored* pilot house for the use in action.

90. Counter.—That part of a ship's afterbody extending from the waterline to the knuckle.

91. Countersinking.—The conical drilling out of a hole after having been punched.

92. Crown of Beam.—See "Beam, Crown of."

93. Dead Flat.—Same as midship section.

94. Dead Rise.—The angle which the straight portion of the bottom of floor of the midship section makes with the base line; it is generally expressed by the number of inches to a certain number of feet measured on the base line, or sometimes it is given as a proportion to the ship's greatest half breadth.

95. Deadwood.—The triangular shaped part forming the connection between keel and stem, and keel and sternpost in wooden ships. Its siding size is the same as that of the keel.

96. Decks.—The several horizontal, or nearly horizontal platforms in ships, arranged at various heights, and distinguished by different names according to their situations and purposes.

97. Deck Light.—A small opening in a deck for the admission of light and sometimes for ventilation, fitted with a thick glass, fixed or removable.

98. Deck Plan.—A plan view of a deck showing the outline or sidelines of the deck and all arrangements and details on the same.

99. Deck Plate.—An arrangement provided in the deck by means of which one pump, principally a large hand pump, may be made to draw water from several compartments.

100. Deck Socket.—A socket fitted in the deck to receive the upper end of a rod arranged to manipulate a watertight door, and provided

with a tell-tale arrangement worked by the rod, which shows whether the door is open or closed.

101. DECK PIPES.—Pipes fitted in the decks for the passage of the chain cables to the lockers. They are generally made of cast steel and located under the after side of the windlass.

102. DECK STRINGERS.—Wide continuous plates placed upon the extremities of each tier of beams. Their principal functions are:

1st. To assist in connecting the deck beams to the side of the ship.

2d. To stiffen the shell plating in the vicinity of the stringer.

3d. To contribute longitudinal strength to the ship.

103. DIAGONAL ARMOR.—See "Armor, Diagonal."

104. DIAGONAL TIE PLATES.—Plates laid diagonally from side to side of the ship, riveted to the beams and butt strapped to the stringers and longitudinal tie plates. They are chiefly of value in resisting the strains communicated to the deck by the masts, for which reason they are fitted in sailing vessels only.

105. DIAMETRAL.—The vertical longitudinal plane through the middle of the ship, dividing it into two symmetrical halves, the boundary lines being the sternpost, keel, stem and upper deck.

106. DIAMOND PLATES.—Diamond shaped small plates applied to strengthen the connections of certain parts of framing, such as continuous and intercostal parts standing at right angles.

107. DOCKING KEELS.—Heavy wooden keels fitted on large ships with comparatively flat floor at some distance from the flat center keel plate, and extending for nearly half the ship's length. Their lower edge is in the same horizontal plane with the center keel, so that in docking, etc., they serve as additional supports.

108. DOGS.—Bent pins, for the purpose of holding angle bars, etc., in position on the bending slab. Their short arms are driven into the holes of the bending slab, while their longer arms rest on the horizontal flange of the angle bar.

109. DOUBLE BOTTOM.—The space between the outer bottom and inner bottom plating.

110. DOUBLE RIVETED EDGE STRIPS.—The strip joining the edges of two flush plates, having two rows of rivets on each side of the seam.

111. DOUBLE RIVETED LAP JOINT.—When the edge of one plate laps the edge of another plate, the lap being secured by a double row of rivets.

112. DOUBLE STAPLE ANGLE.—Two staple angles back to back with plate between, used for connecting solid floor-plates in watertight frames to the inner and outer plating and the longitudinals.

113. DOUBLING STRAKES.—A second strake of plating in thickness, in places where additional strength is required, such as the sheer and bilge strakes amidships.

114. EDGE STRIPS.—Continuous strips of plate connecting the edges of the strakes. They are used for flush plating only and fitted on the in-

side between the strakes and frames, except in the "Lambs" system of plating, when the strakes fay against the frames, in which case they are fitted to the outside of the plating.

115. EDGE STRIP, DOUBLE RIVETED.—See "Double Riveted Edge Strip."

116. EDGE STRIP, SINGLE RIVETED.—See "Single Riveted Edge Strip."

117. ENTRANCE.—A term applied to the fore part of the ship below the load waterline, denoting her fineness, as, "She has a fine entrance."

118. EVEN KEEL.—A ship having the same draft of water forward and aft, is said to be floating on an even keel.

119. EXFOLIATION.—The gradual wasting away of copper sheathing of ships in sea water.

120. EXHAUST SYSTEM.—A system of ventilation by which impure air is drawn from the various compartments of the ship and exhausted.

121. FALSE KEEL.—A thin keel, made in short lengths, and spiked to the lower side of the main keel of wooden or sheathed ships, as a protection to the main keel, and intended to strip off in case the ship takes the ground.

122. FAY, TO.—To join one piece so close to another that there shall be no perceptible space between them.

123. FAYING SURFACE.—The surface of such parts of the framing of a ship against which the plates or planks fay, or against which they fit in such manner as to leave no openings between the surfaces of the framing and plating.

124. FLANGED PLATE.—A plate having one or more of its edges flanged, the flange serving as a substitute for an angle iron, thus saving weight and labor, or if not riveted, it prevents buckling of the plate under strain.

125. FLARING.—A term used particularly to denote the shape of a ship's bow. A ship is said to have a flaring bow when the latter rapidly increases in fullness from the waterline toward the rail. It is the reverse of "tumble home."

126. FLAT PLATE KEEL.—A keel formed of one or two thicknesses of continuous flat plates, deriving its longitudinal strength from a deep vertical center through plate, which is connected thereto by continuous angle bars, one on each side.

127. FLOAT VALVE, AUTOMATIC.—See "Automatic Float Valve."

128. FLOOR HEADS.—The extreme ends of the floor plates, at the junction of the frame and reverse angle irons.

129. FLOOR PLATE.—A curved plate forming part of the frame, extending from bilge to bilge across the keel. Its lower edge is riveted to the frame angle bar and its upper edge to the reverse bar. Its purpose is to effectively strengthen the ship's bottom.

130. FLUSH JOINT.—A joint made by two plates, angles, etc., arranged so as to form a continuous fair surface by means of a seam or butt strap.

131. FLUSH PLATING.—By this system the outer surface of the shell plating is smooth, the edges and butts being united by edge strips and butt straps on the inside.

132. FORE BODY.—That portion of the ship's body forward of the midship section or dead flat.

133. FORE AND AFT.—In the direction of the ship's length, ranging from end to end.

134. FORE AND AFTER HOODS.—The end plates of a shell-strake which terminate upon the stem or sternpost.

135. FORE FOOT.—The lower end or heel of the stem which connects to the keel.

136. FORE PEAK.—The compartment just abaft the stem and below the lowest deck.

137. FRAME, CANT.—A frame *not* standing normal to the longitudinal vertical middle plane, but canted so as to be nearly normal to the outer plating. In metal ships they are only used to form the stern.

138. FRAMES.—Ribs or skeletons made to required varying forms, serving as a strengthening and support for the shell plating. They generally consist of: a frame angle bar, a floor plate, and a reverse angle bar, securely riveted together.

139. FRAME, REVERSE.—"See Reverse Frame."

140. FRAME SPACE.—The distance between the moulding planes of the frames in metal ships.

141. FRAME, SQUARE.—A frame standing normal or at right angles to the longitudinal vertical middle plane of the ship, either extending across the keel as in bar-keel ships, or being made in two parts abutting against and riveted to the vertical keel.

142. FRAMING, LONGITUDINAL.—"See Longitudinal Framing."

143. FRAMING, TRANSVERSE.—See "Transverse Framing."

144. FREEING PORTS.—Ports about 3 feet long by 18 inches deep in the bulwarks for the purpose of rapidly freeing the decks of water when the scuppers are not sufficient to carry it off; with shutters hinged on the upper edge. In warships they are seldom fitted.

145. GARBOARD STRAKES.—The garboards are the strakes of plating next to the keel. With projecting or bar keels they are flanged against the keel in all cases; in the case of flat keel plates their inner edge meets the outer edge of the inner flat keel plate and the overlap of the outer keel plate forms the seam strap.

146. GLACIS PLATES.—Sloped armor plates worked around the hatches on the protective, armored or watertight decks.

147. GRATING, ARMOR.—See "Armor Grating."

148. GUDGEONS.—The lugs on the after side of the sternpost or rudder-post, bored out to receive the pintles by which the rudder is hung.

149. GUN SPONSONS.—Projections on the side of a ship, level with the deck, on which guns are mounted, for the purpose of giving them a

greater train. They are supported by an angle iron frame-work, plated over, and connected to the ship's side by brackets and angle irons.

150. GUN SUPPORTS.—Special framing of girders and stanchions fitted under gun positions.

151. GUNWALE ANGLE BAR.—A stout, continuous angle bar connecting the stringer plate to the sheer strake.

152. GUSSET PLATE.—A plate, generally of triangular form and riveted to the split end of a frame bar, etc., so as to afford a substantial connection to a deck, etc.

153. GUTTER PLATE.—A middle line flat plate worked on top of the floors and riveted to the reverse frames and lug pieces. The same as a "Flat Keelson Plate."

154. GUTTER WATERWAY.—A water course on the stringer plate running parallel to the ship's side and bounded by the gunwale and waterway angle bars.

155. HALF BEAMS.—Beams used in the wake of hatches; they are less than half the length of full beams and run from the side of the ship to the hatch carling only.

156. HALF SIDING.—The half thickness of the stem, sternpost and keel, set off parallel to the middle line in the half breadth and body plans for the ending of the waterlines, etc.

157. HALF SOLID FLOORS.—Solid floor plates lightened by round or oval holes for the purpose of saving weight or to give access to compartments of the double bottom.

158. HAMMOCK BERTHING.—A light trough built on top of the rail for the purpose of stowing hammocks. It may itself be so deep as to form the bulwarks.

159. HAMMOCK NETTING.—Same as "Hammock Berthing."

160. HARPINS.—Harpins serve the same purpose as ribbands, but in places where the latter cannot be bent around on account of too great a curvature. They are shaped to the exact form of the lines to which they are to be applied, generally the rail and deck lines, and are bevelled so that the frames lay closely against them. They are only used from the stem aft, and around the stern, and overlap, by several frame spaces, those parts of the framework which have been faired by ribbands.

161. HATCHES.—The openings in a ship's decks which are used for striking up or down cargo, as well as those which are used by the people on board as a means of communication between the different decks.

162. HATCH COAMINGS.—Raised rims around the hatch openings, standing above the deck, to prevent water or loose articles from rolling into them. The athwartship sides of the hatch coamings are distinguished as "head ledges" from the fore and aft side called "coamings."

163. HATCH, BATTLE.—See "Battle Hatch."

164. HATCH, COMPANION.—See "Companion Hatch."

165. HAWSE HOLES.—The cylindrical holes in the bow of a vessel, on each side of the stem, into which the hawse pipes are fitted.

166. HAWSE PIPES.—The cast steel or iron pipes fitted into the hawse holes, having heavy rounded flanges against the bow and deck, to take the chafe of the chain cables.

167. HEAD.—The upper end of any part of a ship's framing, viz.: the head of a frame, or head of the stem, etc.

168. HEAD LEDGES.—The athwartship pieces of the hatchway framing.

169. HEEL.—The lower end of any part of a ship's framing, viz.: heel of a frame or heel of the stem, etc.

170. HEEL PIECES.—Short pieces of angle irons serving as butt straps when the frame angle bar is butted at the middle line. They are placed on the side of the floor plate opposite to that to which the frame angle bar is riveted.

171. HOLD BEAMS.—They have no deck laid on them and for convenience of stowage are more widely spaced than other tiers of beams. For this reason they have to be made of extra strength and the hold beam stringer is additionally stiffened by angle irons and other means.

172. HOLD STRINGER.—Stringers in hold are the keelson-like longitudinal arrangements fitted on the inside of the frames between the lowest tiers of beams and the bilge keelson.

173. HOODS, FORE AND AFTER.—See "Fore and After Hoods."

174. HORN.—To horn the frames of a ship means to adjust them so as to bring their moulding plane at right angles to the longitudinal middle line of the keel.

175. HULL.—The framing of the ship, the watertight envelope, the decks, etc.; in fact the body of the ship complete, but without masts, yards, sails, rigging and other equipments.

176. INNER BOTTOM.—The inner skin or watertight plating secured to the reverse frames extending through the boiler and engine spaces and forming the upper surface of a volue called the double bottom.

177. INNER FRAME ANGLE IRON.—Same as "Reverse Frame Angle Iron."

178. INTERCOSTAL.—A part, which, on account of obstructions, etc., cannot be worked continuous and therefore is worked in short lengths between the obstructions.

179. INTERCOSTAL KEELSON.—It consists of vertical plates fitted between the floor plates and connected thereto by an angle iron on each end, in combination with a continuous bulb plate and two angle irons by which it is secured to the reverse frames, or a plate keelson having angle irons both at the top and bottom; the continuous plate being scored down over the floors sufficiently to connect to the intercostal plates by one row of rivets.

180. KEEL.—It is the lowest part or backbone of the ship, connecting the stem and sternpost. It is the first part of the ship laid on the building blocks and the foundation for the whole structure.

181. KEEL, BAR.—See "Bar Keel."

182. KEEL, BILGE.—See "Bilge Keel."

183. KEEL, FLAT PLATE.—See "Flat Plate Keel."

184. KEEL, SIDE BAR.—See "Side Bar Keel."

185. KEEL BLOCKS.—The foundation for a ship while under process of building, consisting of a series of heavy blocks of gradually varying height, on which the keel of the ship is laid.

186. KEELSON.—A longitudinal device to prevent local deformation of the bottom due to excess either of weight or buoyancy and to distribute over a considerable length the effect of concentrated loads, etc.

187. KEELSON, BILGE.—See "Bilge Keelson."

188. KEELSON, INTERCOSTAL.—See "Intercostal Keelson."

189. KEELSON, MIDDLE LINE.—See "Middle Line Keelson."

190. KEELSON, SIDE.—See "Side Keelson."

191. KEELSON PLATE.—The same as the "Vertical Keel Plate" in ships of war. A term used for merchant ships only.

192. KINGSTON VALVE.—A common form of sea-valve in the side of a ship under water to which the sea-suction of the pump leads. Water enters when the valve is pushed outward from its seat.

193. KNEE PLATE.—A triangular shaped plate used to connect the end of a beam to the side of the ship, when no knee or arm is formed on the beam.

194. KNUCKLE.—The sudden angle or the point of change of direction made by the stern framing in many ships, at or just below the deck.

195. LAP JOINT.—The joint made by two plates by lapping the edge of one over that of the other.

196. LAP JOINT, DOUBLE RIVETED.—See "Double Riveted Lap Joint."

197. LAP JOINT, SINGLE RIVETED.—See "Single Riveted Lap Joint."

198. LAYING OFF.—The process of enlarging the ship's lines from the drawing to their full size on the mould loft floor.

199. LIGHTENED PLATE FRAME.—A frame having floor plates with openings cut in them for the purpose of saving weight and to give access to adjoining compartments. A construction stronger than the bracket frame.

200. LIMBER HOLES.—Circular holes in the lower part of the floor plates, just above the vertical flange of the frame angle bar and in the vicinity of the middle line keelson or vertical keel, for the purpose of draining the water from frame space to frame space. They range from 2 to 3½ inches in diameter.

201. LINERS.—Narrow pieces of plate fitted between the raised strakes and the frames, extending from edge to edge of the two underlying

inner strakes. With the clinker system of plating the liners are necessarily of wedge form. When consecutive inner strakes are of different thickness, the liners to the intermediate outer strake will be slightly tapered.

202. LOCAL STRENGTH.—The capacity to resist forces applied over relatively small areas, such as the fluid pressure tending to bulge the skin of the bottom plating between the frames, the point of a rock in taking the ground, or of a ram in action, etc.

203. LONGITUDINALS.—They are similar in construction to the continuous vertical keel in ships with flat keel plates and are placed at intervals between the latter and the margin plate at the bilge, in unarmored ships, and between the vertical keel and armor shelf in armored ships, but are continuous only throughout the double bottom space, beyond which they are worked intercostal. Their position is normal to the shell plating.

204. LONGITUDINAL FRAMING.—It includes all those structural parts of a vessel which run in a fore and aft direction, and afford longitudinal strength.

205. LONGITUDINAL TIE PLATES.—Continuous plates laid all fore and aft on each side of the hatchways on each tier of beams, except when an iron or steel deck is laid. They serve to keep the beams to which they are riveted in the same relative position to each other and to resist their tendency to buckling.

206. LUG PIECES.—Short pieces angle iron of the same size as, and riveted back to back to the reverse angle bars in the wake of keelsons, bilge and side stringers, etc. Their object is to give a more effective connection between the latter and the frames.

207. MAIN FRAME ANGLE IRON.—The outer angle iron of a frame to which the shell plating is riveted.

208. MAKER.—A tool used in caulking metal ships. It is used after a split has been made in the edge of the plate, so as to drive the piece split tightly against the adjoining plate.

209. MANGER.—A space abaft the hawse holes formed by an athwartship coaming so as to prevent the water entering through the hawsepipes from rushing aft on deck.

210. MANGER BOARD.—The athwartship coaming forming the after boundary of the manger.

211. MANHOLES.—Hatches smaller than scuttles; when so small as to barely admit a man.

212. MANIFOLD.—A valve chest or suction box into which lead pipes from the different compartments of the double bottom, etc., and arranged so that one pump can be made to draw water from any one of the compartments connected with it.

213. MARGIN PLATE.—The outermost strake, on each side, of the inner

bottom plating, having a watertight connection, either by flange or angle bar, with the shell plating.

214. Mast Partners.—The special framing and plating between the deck beams to form the mast-hole.

215. Mast-Steps.—The forgings or steel castings secured to the keelson or to a lower deck, into which the heel of the masts are stepped.

216. Middle Line Keelson.—A continuous plate keelson running fore and aft above the center of the keel. It is secured to the reverse frames and lug pieces by an angle bar on each side, its upper edge being strengthened by two similar angle bars, which are sometimes capped with a flat plate, called a rider plate. Whenever an intercostal keelson is fitted between the floors, the plate keelson is scored down over the floors and is riveted to the upper edge of the intercostal plates.

217. Midship Section.—The vertical transverse section, having the greatest breadth at the load waterline, and generally the largest area and situated at or near the middle of length, also called the "Dead Flat" and denoted on the plans by the symbol [illegible].

218. Middle Body.—That portion of the ship's body amidships, having a uniform cross-section.

219. Molded Form.—The form of the ship when the plating or planking is removed, or the form over the frames of the ship.

220. Molding Edge.—The line or curve defining the form of the frame in its molding plane.

221. Molding Plane.—The plane which traverses the middle of a wooden frame, or the back of the standing flange of the outer or frame angle bar in a metal frame.

222. Mold Loft.—A large loft with smooth and level floor on which the lines of ship are drawn to full size and faired.

223. Molds.—Patterns made of thin pine boards to conform exactly to the shape of frames or other parts of a ship, by the aid of which the same can be bent or fashioned to the required form.

224. Neutral Axis.—The neutral axis is an imaginary line of no strain, passing longitudinally through a plate, body, etc. For a plate of uniform width and thickness it coincides with the middle line, but when not of uniform width or thickness, it is the line passing through the center of gravity of the cross-section. At the neutral axis there is neither elongation nor compression.

225. Non-Return Valve.—A valve for drainage purposes which permits the flow of water in one direction while preventing its passage in the opposite direction.

226. Outer Bottom.—The plating or watertight envelope secured to the outside of the frames, giving the structure the capacity of flotation.

227. Outside Form.—The form of the ship over the plating or planking forming the watertight skin or envelope.

228. OUTER FRAME ANGLE IRON.—Same as "Main Frame Angle Iron."

229. PANTING.—A flexibility, or moving in and out of the shell plating under local pressures. It is most likely to occur in the comparatively flat parts of the plating, such as the bow, the rounded bottom amidships being more adapted, by its form, to resist alteration of shape from water pressures.

230. PANTING STRINGERS.—Additional stringers fitted in the bow to stiffen the plating and frames against the tendency to flexibility developed in that part of the ship on account of the diminished curvature.

231. PARTIAL BULKHEADS.—Same as web frames. Sometimes, however, the sides of vessels between a main and middle or lower deck are stiffened by partial bulkheads which do not extend into the hold.

232. PASSING SCUTTLE.—A scuttle for passing ammunition from one deck to another.

233. PASSING STRAKE.—A continuous strake between butts in the same vertical plane.

234. PICKLING.—A process of removing the mill scale from steel plates. The plates are placed on edge for a few hours in a weak hydrochloric acid bath. After being taken out, a stream of water is turned on them, their surfaces being brushed at the same time to remove the scale loosened by the action of the acid.

235. PILLARS.—The vertical supports of the deck beams, having their heel riveted to the middle line keelson and the palm formed on the head, riveted to the deck beam. They are either solid or hollow, but in the latter case have solid heads and heels.

236. PILOT HOUSE.—A small deck house upon the upper or bridge deck enclosing the steering wheel and steering compasses, from which the vessel is steered or conned.

237. PINTLES.—The round pins or bolts in the forward edge of the rudder frame by which the rudder is hung and around which it moves. They fit snugly into the gudgeons on the after side of the stern or rudder post.

238. PITCH OF RIVETS.—See "Rivets, Pitch of."

239. PLATE FRAME, LIGHTENED.—See "Lightened Plate Frame."

240. PLATE BUTT.—See "Butt Plate."

241. PLATE, FLANGED.—A plate having one or more of its edges flanged, the flange serving as a substitute for an angle iron, thus saving weight and labor, or if not riveted, it prevents buckling of the plate under strain.

242. PLATE, KNEE.—See "Knee Plate."

243. PLENUM SYSTEM.—A system of ventilation by which fresh air is forced into the ship.

244. PLUMB.—To plumb the frames cf a ship means to adjust them so

as to bring their molding planes to their proper angle with the keel, or perpendicular to the waterline.

245. PROFILE INBOARD.—A vertical longitudinal middle section showing the decks and the interior arrangements of the ship.

246. PROFILE OUTBOARD.—A broadside view of a ship, showing its boundary lines and all arrangements and details visible in that condition.

247. PROTECTIVE DECK.—An iron or steel deck, sometimes arched, or inclined at the sides, usually below the waterline at the side, and slightly above the same at the middle line, plated with protective plating sufficiently thick to withstand the effect of the projectiles under oblique impact.

248. PROTECTIVE DECK, UNDERWATER.—A heavily plated deck at the ends of a ship, extending from the diagonal armor to the stem and stern respectively, situated at the height of the armor shelf. Its purpose is the protection to buoyancy for the ends of the ship. That part forward of the diagonal armor generally has a gentle slope forward toward the ram, so as to increase the strength of the bow for ramming.

249. QUARTER STANCHIONS.—The pillars supporting the deck beams, whenever two of them are used for each beam and they are placed one on each side of the middle line.

250. RABBET.—A groove formed in the stem of iron or steel ships, equal in depth to the thickness of the plating, so as to form an abutment for the ends of the bottom and side plating. In wooden ships not only the stem, but the keel and sternpost are also rabbeted.

251. RAISED AND SUNKEN PLATING.—A system by which alternate strakes of plating fay against the frame angles, while the intermediate strakes overlap their edges. Liners are required for the overlapping or raised strakes. The overlapping edges are either single or double riveted. Butt straps are fitted on the inside, those for inside strakes extending the entire breadth of the plates, those for raised strakes fitted between the edges of inner strakes only.

252. RAKE.—To incline, as the inclination of the stem or sternpost, and masts from a vertical line.

253. RAM.—The projecting under water part of a ship's stem, for the purpose of forcing or ramming in the sides of other ships.

254. RAM BOW.—A ship's bow fitted with a stem which projects below water and recedes at the head, for the purpose of ramming.

255. RAM PLATE.—A heavy horizontal plate projecting outside the general surface of the bottom plating, to strengthen the stem for ramming and to resist the wrenching stresses when striking obliquely.

256. RAZING.—The operation of cutting in the ship's lines on the mould-loft floor or on the scrive board with a razing knife or scriber, so that they cannot be easily extinguished.

257. REEDING TOOL.—A tool used in caulking metal ships, a finishing tool applied after the splitter and maker.

258. REVERSE FRAME.—A part of the frame, formed by an angle bar slightly smaller in section than the main frame bar. It is riveted to the upper edge of the floor plate on the side opposite to the main frame bar, and back to back to the latter above the head of the floor.

259. RIBBANDS.—Long straight pieces of heavy scantling, but sufficiently flexible to bend to long and easy curves; they are bent around the frames for the purpose of fairing them after they have been erected on the keel, and to keep them to their proper places.

260. RIBBAND LINES.—The lines to which the ribbands are bent around the frames of the ship, after they have been erected. They are generally identical with the diagonal lines and sheer lines.

261. RIDER PLATE.—The same as the "gutter plate" in ships with a continuous vertical keel. Also the flat plate covering the two upper angles in a middle line single plate keelson.

262. RISE OF FLOOR.—Same as Dead Rise.

263. RIVET, THROUGH.—See "Through Rivet."

264. RIVETING, CHAIN.—When rivets are placed in parallel rows with corresponding rivets opposite each other.

265. RIVETING, ZIG-ZAG.—When rivets are placed in parallel rows, the rivets of one row being spaced midways between those of the adjoining row.

266. RIVETS, DISTANCE OF.—The distance from center to center of the rows of rivets in double or treble chain riveting. It depends upon the size of the rivets used and the standard rule is 2½ times their diameter.

267. RIVETS, PITCH OF.—The distance between the centers of any two rivets in the same row.

268. ROUND UP OF BEAMS.—Same as "Crown of Beams."

269. RUDDER POST.—The post abaft the sternpost or body post in single screw ships, to which the rudder is hung.

270. RUN.—A term applied to the after part of the ship below the waterline, denoting her fineness, as: "She has a full run."

271. SADDLE.—The semi-circular supports for Scotch boilers.

272. SCANTLING.—The dimensions of the cross-sectional area of the parts constituting the framing of a ship.

273. SCARPHING.—The uniting of two pieces by lapping one piece on the other; the lapped parts to be reduced in thickness in such a manner that the two pieces shall appear as one, with a continuous and smooth surface on each side.

274. SCREW APERTURE.—The opening between the sternpost and rudderpost in single screw ships.

275. SCRIVE BOARD.—The scrive board consists of a number of seasoned planks, secured edge to edge by clamps at the back; the edges to be close jointed and the board to be large enough to receive a copy of the body plan to full size. On it are copied, from the body plan, all the lines necessary to determine the shape of the various parts of the ship's framing, etc.

276. SCUTTLES.—Small hatches in the decks.

277. SCUTTLE, COALING.—See "Coaling Scuttles."

278. SCUTTLE, PASSING.—See "Passing Scuttle."

279. SEATING.—That part of the frame angle bar which rests on the keel.

280. SET IRON.—A flat plate bar of soft iron, varying in section from about 1¼″ x ⅜″ to 2″ x ⅝″, for the purpose of transferring the curvature of the frames, etc., from the scrive board to the bending slab.

281. SHAFT ALLEY—An alley in the after part of the ship, through which the propeller shaft passes, formed by two longitudinal bulkheads.

282. SHAFT BEARERS.—The additions to the ordinary framing of the ship on which the journals for the propeller shaft are fastened.

283. SHAPES.—Rolled bars of iron or steel of various cross-sections, used in the construction of ships.

284. SHEATHED SHIPS.—Iron or steel ships having their shell plating sheathed with wood to a height of 3 or 4 feet above the load waterline, to allow of their being coppered.

285. SHEER PLAN.—A longitudinal elevation or side view of a ship, showing the boundary lines, viz.: the keel, the contour of the stem and stern, the sheer lines and different decklines at side, the frame stations, waterlines, bow and buttock lines, and sometimes a portion of the diagonal lines near the stem and stern.

286. SHEER STRAKE.—The sheer strake is the uppermost strake of the shell plating, and is therefore adjacent to the upper deck beams and stringer plate, forming, in conjunction with the latter and its angle iron bars, a rigid girder-like arrangement at that part of the vessel where hogging and sagging movements are first experienced.

287. SHELF PLATE.—Same as "Armor Shelf."

288. SHELL PLATING.—The watertight envelope or skin of metal plates, worked over and riveted to the frames, giving the structure strength and the capacity of flotation.

289. SHIFT OF BUTTS.—A term used to denote the disposition of the butts of plating angles, etc., so as to ensure uniform strength.

290. SHOE.—In twin screw ships it is the flange on each side of the horizontal part of the sternpost, on which the struts for the support of the after end of the propeller shafts rest. In single screw ships it is the horizontal connections between the heels of the sternpost and rudderpost.

291. SHORES.—Heavy pieces of scantling placed vertically or obliquely under the object to be supported or to be held in place. When used on ships, their upper end is generally placed under the ribbands or harpins.

292. SHUTTERS, BATTLE.—See "Battle Shutters."

293. SIDE BAR.—A part of a side bar keel. The plate on each side of the lower part of the vertical keel, of sufficient thickness to make the combined three thicknesses equal to that of an ordinary bar keel.

294. SIDE BAR KEEL.—A keel composed of a deep center through plate, re-enforced on each side, at its lower edge, by plates of the same depth as a bar keel, the collective thickness of all the plates to be fully equal to the bar keel of a ship of equal size.

295. SIDE KEELSONS.—The keelsons fitted on each side of the middle line keelson, about midway between the latter and the commencement of the bilge curvature.

296. SIDE STRINGER.—A keelson-like arrangement between the bilge stringer at the upper turn of the bilge and the lowest deck. According to the size of the vessel it consists either of a pair of angle irons riveted back to back; a pair of angle irons with a bulb plate between them; or a plate with double angle irons on both edges. In some cases intercostal plates are fitted to them, attached to the shell plating.

297. SIDING.—The siding size of any part of a ship is its thickness taken at right angles to its moulding plane, viz.: the siding of the stem is its thickness athwartships; that of a frame its thickness in a fore and aft direction.

298. SIGHT EDGES.—The edges of the raised strakes of the shell plating.

299. SINGLE RIVETED EDGE STRIP.—The strip joining the edges of two flush plates, having one row of rivets on each side of the seam.

300. SKEG.—The continuation of the keel beyond the sternpost whenever it droops much below the keel-line as a protection for the screw and for the purpose of taking the heel of the rudder.

301. SKID BEAMS.—Beams on which to stow the heavier boats.

302. SKIN DRAFT.—The draft of water exclusive of the projecting keel.

303. SKYLIGHT.—A permanent or removable cover with hinged sashes, fitted over a hatch, intended solely for admission of light and air.

304. SLUICE VALVE.—A small watertight door in the watertight floors of a frame, etc., usually operated by a rod from one of the decks.

305. SOUNDING TUBES.—Small tubes extending vertically from the deck downwards to within a short distance of the keel, into which the sounding rods are lowered to ascertain the depth of water in the ship.

306. SPARRING.—Battens running in a fore and aft direction, secured to the reverse frames to prevent the cargo from resting against the shell plating.

307. SPLINTER OF SCREEN BULKHEADS.—Heavy bulkheads between the guns on battery decks, for the purpose of localizing the damage by splinters from the side, if penetrated.

308. SPLITTER.—A tool used in caulking metal ships; to make a split in the edge of a plate, after which a tool called a "maker" is used to drive the piece so split tightly against the adjoining plate.

309. SPRING OF BEAM.—Same as "Crown of Beam."

310. SQUARE BODY.—The square body comprises all those frames which stand at right angles to the center line of the ship.

311. SQUARE FRAME.—A frame standing normal, or at right angles to the longitudinal vertical middle plane of the ship, either extending across the keel as in bar-keel ships, or being made in two parts abutting against and riveted to the vertical keel.

312. STANDING BEVEL.—When it forms an obtuse angle.

313. STAPLE ANGLES.—Angle irons bent staple fashion, having both ends bent down or up, used for connecting solid floor plates in water-tight frames to the inner and outer plating and the longitudinals.

314. STEALERS.—Strakes of shell plating which terminate at some distance from the bow or stern, by merging two strakes into one where the termination occurs.

315. STEM.—The heavy forging or casting forming the foremost boundary of the ship, being a continuation of the keel to the highest deck.

316. STERN.—The after extremity of a ship, the overhang beyond the sternpost or rudderpost.

317. STERN FRAME.—The sternpost or bodypost, and rudderpost forged or cast in one piece, their connection at the lower ends being called the "shoe" and that for the upper ends ends the "arch."

318. STERN FRAMING.—The frames forming the stern overhang beyond the sternpost. They are secured to the transom floor plate, from which they radiate, by means of bracket plates and short angle irons.

319. STERNPOST.—The heavy forging or casting forming the after boundary of the ship. Its lower part is generally horizontal, or nearly so, and forms a continuation of the keel, the upper part ending at one of the decks and being connected thereto.

320. STERN TUBE.—A tube through which the propeller shaft passes, extending from the stern or body post to the stuffing box bulkhead.

321. STIFFENERS.—Angle iron or T iron bars for the purpose of stiffening transverse and longitudinal bulkheads. In most cases they are worked vertically.

322. STRAKE.—A continuous plank or plate composed of several lengths fitted end to end, extending from stem to stern.

323. STRAKE, PASSING.—See "Passing Strake."

324. STRAKES, RAISED.—See "Raised and Sunken Plating."

325. STRAKES, SUNKEN.—See "Raised and Sunken Plating."

326. STRENGTH, LOCAL.—See "Local Strength."

327. STRENGTH, STRUCTURAL.—See "Structural Strength."

328. STRUCTURAL STRENGTH.—The capacity of a ship's hull to resist the effect of unequal distribution of weight and buoyancy, resulting in a class of forces applied more or less smoothly over large areas, producing shearing forces and bending moments of gradually varying amount.

329. STUFFING BOX BULKHEAD.—The aftermost bulkhead to which the inner end of the shaft tube as well as the stuffing box are attached.

330. SUPERSTRUCTURE, CENTRAL.—An erection on the upper deck, continuous along the middle of length of the ship.

331. TEMPLATE.—A transfer mould used simply because a few wooden battens nailed together are more conveniently handled than a heavy plate or bar.

332. TEMPLATING.—A process devised for the purpose of avoiding the labor which would be involved in marking the rivet holes upon plates, angle bars, etc., by first holding them in the place where they are ultimately to be riveted.

333. THROAT OF FLOORS.—The upper edge of the floor plates at the middle line.

334. THROATING LINE.—The line or curve passing through the throat of the floors, as shown in the sheer plan or profile.

335. THROUGH RIVET.—A rivet which passes through the materials to be united, being long enough to have a head formed on it by hammering.

336. THRUST BLOCK OR THRUST BEARING.—The addition to the ordinary ship's framing of certain longitudinals and transverse bearers, etc., by means of which the thrust of the propeller shaft is transmitted to the ship instead of to the engines.

337. TIE PLATES.—Narrow strakes of plating applied to keep deck beams and other parts of framing in their relative position to each other, to prevent their buckling and to strengthen them as a whole.

338. TIE PLATES, DIAGONAL.—See "Diagonal Tie Plates."

339. TIE PLATES, LONGITUDINAL.—See "Longitudinal Tie Plates."

340. TRANSOM OR TRANSOM FRAME.—The aftermost frame of the square body, which is riveted to the head of the sternpost, and from which the stern framing radiates. Its floor plate is deeper than the midship floors so that the stern framing may be efficiently secured to it by deep bracket plates.

341. TRANSVERSE.—The position of anything when placed at right angles to the keel.

342. TRANSVERSE FRAMING.—It includes all those structural parts of a vessel giving transverse or athwartship strength.

343. TRIM.—A term used to denote how a vessel floats, viz., "She trims by the head" or "She trims by the stern."

344. TRIMMING TANKS.—Tanks in the extreme underwater ends of a ship, which can be filled or emptied at will, to effect a change of draft, or change of trim.

345. TRUNK.—An enclosure or casing around hatches, extending between two decks, as fitted around boiler and engine room hatches.

346. TUMBLE HOME.—A term used particularly to denote the shape of a ship's side. A ship is said to tumble home when her side is turning in as it approaches the rail; when her breadth above water is uniformly decreasing.

347. TURN OF THE BILGE.—The place of maximum curvature of the outside form along the middle body, where the bottom turns into the side.

348. TURTLE BACK.—A forecastle or poop deck, when the crown of the beam is so very great as to form a reverse sheer, so that the ends of the ship are dropping instead of rising.

349. UNDER BEVEL.—When it forms an acute angle.

350. VERTICAL ARMOR.—See "Armor, Vertical."

351. VERTICAL KEEL PLATE.—A deep, continuous vertical plate, connected with its lower edge to the flat keel plate or keel plates by two continuous angle bars; the extreme ends being connected to the stem and sternpost respectively. In merchant ships it is called the "Keelson Plate."

352. VERTICAL PLATE KEELSON.—The same as the "Vertical Keel Plate" in ships of war. The term is used in merchant ships only.

353. WAIST.—The portion of the upper deck between the poop and forecastle.

354. WALL SIDED.—A ship is said to be wall sided, when the side rises vertically above the waterline.

355. WATER BOTTOM.—The space between the outer bottom and inner bottom plating, so called in merchant ships for its "use for carrying water ballast."

356. WATER COURSES.—Same as "Gutter Waterways."

357. WATERLINES.—Lines which the surface of the water forms with the side of a vessel at various successive depths of immersion parallel to the load waterline; they appear straight in the sheer plan and body plan, while their form or curvature is shown in the half breadth plan.

358. WATERTIGHT BULKHEADS.—Transverse or longitudinal bulkheads, the laps, or seams and butts of which are closely riveted for efficient caulking to make them watertight; the whole to be thoroughly stiffened

by horizontal and vertical stiffeners so as to resist the pressure of water in case one of the compartments is bilged. Their object is to confine any underwater damage to the damaged compartment only.

359. WATERTIGHT FRAMES.—Frames having solid floor plates between the frame bar, reverse bar and the longitudinals, closely riveted for caulking, in ships fitted with a double bottom; thus dividing the double bottom space into a number of watertight compartments. They are generally spaced about 20 feet apart.

360. WATERWAY ANGLE BAR.—An angle bar on top of the upper deck stringer plate running parallel to the gunwale angle bar and forming therewith a gutter watercourse which leads the water to the scuppers. It forms the outline of the wood deck and resists the caulking strains.

361. WEB FRAMES.—Wide transverse frames, or rather, narrow partial bulkheads. They differ from the ordinary frame in so far, that the frame and reverse angles are not riveted back to back, but have a plate between them, the outer edge of the plate being riveted to the frame angle and the inner edge to the reverse angle. Their purpose is to preserve a continuity of strength or stiffness where the same has been interrupted by the necessary omission of beams, etc.

362. WINDLASS BED.—A solid foundation to which the windlass is secured, consisting of heavy plating on the upper as well as lower side of the deck beams, the space between the plates being filled in solid with yellow pine.

363. WING PASSAGE.—A fore and aft passage along the ship's side, formed by a longitudinal bulkhead, the ship's side and the watertight deck above and below.

364. WOOD BACKING.—See "Backing, Wood."

365. ZIG-ZAG RIVETING.—See "Riveting, Zig-zag."

APPENDIX B

NAVAL ARCHITECTURE TERMS NOT INCLUDED IN TEXT OF BOOK

1. ARC OF OSCILLATION.—The total angle swept through by a ship in one oscillation.

2. AXIS OF ROTATION.—The rolling of a ship, when not accompanied by pitching or dipping oscillations, takes place about a longitudinal axis, called the "Axis of Rotation."

3. BUOYANCY.—Buoyancy is the upward pressure exerted by a liquid upon the surface of a body, wholly or partially immersed in it.

The buoyancy depends solely upon the ratio existing between the bulk of the given body and its weight, in other words on its "specific gravity" in relation to the density of the fluid which supports it.

A body will immerse itself until the supporting force, which is represented by the weight of the displaced volume of water, equals and balances the weight of the body. If a body is not of sufficient bulk to displace a volume of water which is equal to its weight, it cannot float but must sink.

A body which is lighter, bulk for bulk, than the water in which it floats, will float partially immersed, and displace a volume of water which is similar in form and equal in bulk to the immersed portion of the body, but in weight the displaced volume of water is equal to the total weight of the body, or, both the body and its contents.

4. BUOYANCY, RESERVE.—See "Reserve Buoyancy."

5. BUOYANCY, WORKING.—See "Working Buoyancy."

6. CENTERS OF BUOYANCY, CURVE OF.—See "Curve of Centers of Buoyancy."

7. CENTER OF EFFORT.—A term applied to sailing vessels only.

The center of application of the propelling impulse of the wind on the sails; or the center of gravity of the surface of all the *plain* sail.

8. CENTER OF FLOTATION.—The axis passing through the center of gravity of the water plane; the axis about which any change of trim takes place.

9. CENTER OF LATERAL RESISTANCE.—The center of gravity of the longitudinal vertical middle plane of the immersed part of a ship, which offers resistance to leeway, when under sail.

10. CHANGE OF TRIM.—A change in the forward and after draft of water of a ship, occasioned by the fore and aft movement of weights already on board; it takes place about the center of flotation, or the axis

through the center of gravity of the waterline. The draft at the center of flotation therefore remains the same, while an increase at one extremity is accompanied by a proportionate decrease at the other.

11. CLASS OF STRESS.—There are three principal kinds of simple stresses, viz.:

I. Thrust of Compression.

II. Pull of Tension.

III. Shear or Tangential Stress.

12. COUPLE, RIGHTING.—See "Righting Couple."

13. COUPLE, UPSETTING.—See "Upsetting Couple."

14. CRANKNESS.—A ship is said to be crank when her metacentric height is small, so that the ship is easily inclined from the upright.

15. CURVE OF CENTERS OF BUOYANCY.—If a vessel be heeled continuously to greater and greater angles, while retaining an invariable volume of displacement, the center of buoyancy will occupy successive positions in a curved locus, called the "Curve of Centers of Buoyancy."

16. CURVE OF DISPLACEMENT.—Same as "Displacement Scale."

17. CURVE OF SECTIONAL AREAS.—A curve sometimes used for calculating the displacement from the areas of vertical sections, represented by ordinates. From a base line representing the length of the ship, ordinates are drawn at points corresponding to the position of the sections, and the calculated areas are set off thereon, to scale. Through the points so obtained a curve is drawn, and the area of this curve represented to scale gives the volume of the displacement. The center of gravity of the plane represents the center of buoyancy of the displacement.

18. CURVE OF TONS PER INCH.—See "Tons per Inch, Curve of."

19. DIPPING.—Dipping is the name given to the vertical oscillatory motion of a ship which is produced by rolling or pitching. On this account it has been termed a "Secondary Oscillation." Dipping produced by rolling results either from the form of the ship's body near the waterline, or from a very low position of the ship's center of gravity.

20. DISPLACEMENT.—The quantity or volume of water displaced by a ship is called her "*Displacement*"; it can be expressed either in cubic feet or tons; a cubic foot of sea-water weighs 64 lbs. and of fresh water 62.5 lbs., therefore a ton is equal to 35 cubic feet of sea-water or 35.9 cubic feet of fresh water.

21. DISPLACEMENT.—See "Light Displacement."

22. DISPLACEMENT, LOAD.—See "Full Load Displacement.

23. DISPLACEMENT, NORMAL.—See "Normal Displacement."

24. DISPLACEMENT, USEFUL.—See "Useful Displacement."

25. DISPLACEMENT, VOLUME OF.—The volume of water displaced by a ship when afloat.

26. DISPLACEMENT, WEIGHT.—The weight of the volume of water displaced by a ship when afloat. It is generally expressed in tons of 2240 lbs.

$$\text{Weight Displacement} = \frac{\text{Volume of Displacement in cubic feet}}{\text{Number of cubic feet of water to the ton.}}$$

27. DYNAMICAL STABILITY.—The amount of mechanical work necessary to heel a ship over to any angle from the upright position, is called the dynamical stability at that angle. Work is said to be done when a resistance is overcome through space, and is usually expressed in foot-tons when dealing with large amounts.

28. ELASTICITY.—Elasticity is that property of a body by which it retains, and seeks to retain, a certain determinate volume and figure at a given pressure.

29. ELASTIC STRENGTH.—Elastic strength is the utmost amount of stress which a body can bear without set.

30. EQUILIBRIUM, NEUTRAL OR INDIFFERENT.—Suppose a ship held in a slightly inclined position by an external force. If, upon the removal of this external force she remains in the slightly displaced position, without any tendency to return towards, or move farther from its original position of rest, she is said to be in neutral or indifferent equilibrium for the given direction of inclination.

31. EQUILIBRIUM, STABLE.—If a ship, when slightly inclined in any particular direction from her position of rest, returns towards that position when the inclining forces are removed, she is said to be in stable equilibrium for the given direction of inclination.

32. EQUILIBRIUM, UNSTABLE.—Suppose a ship held in a slightly inclined position by an external force. If, upon the removal of this external force the ship moves farther from its original position of rest, she is said to be in unstable equilibrium for the given direction of inclination.

33. FACTORS OF SAFETY.—Factors of Safety are of three kinds:

I. The ratio in which the breaking load exceeds the proof load.

II. The ratio in which the breaking load exceeds the working load.

III. The ratio in which the proof load exceeds the working load.

Unless otherwise stated—when the term "Factor of Safety" is used—it is to be understood in the second of these senses.

34. FLOTATION, CENTER OF.—See "Center of Flotation."

35. FLOATING POWER, TOTAL.—The total floating power of a ship consists of "utilized" buoyancy, which is counteracted or balanced by its weight or displacement, and of "reserve" buoyancy, which is the floating power of the freeboard, or that portion of the hull which is not constantly immersed, her safety at sea depending very much on the ratio existing between the utilized and reverse buoyancy.

36. **Freeboard.**—The height of the ship above the load waterline, taken amidships to the upper edge of the deck-planking at the side.

37.—**Full Load Displacement.**—By a full load displacement is meant the displacement of the ship, complete in every respect and ready for sea, the vessel having on board her full complement of officers and men, together with their belongings, full provisions, full allowance of ammunition, bunkers and fuel oil tanks full, reserve feed water tanks full, all stores and consumables full allowance in accordance with the allowance books.

38. **Gravity, Center of.**—See "Center of Gravity."

39. **Gross Register Tonnage.**—See "Tonnage, Gross Register."

40. **Hull, Weight of.**—See "Weight of Hull."

41. **Inclination, Skew.**—See "Skew Inclination."

42. **Initial Stability.**—The resistance offered to inclination from the upright as measured by the metacentric height, as distinguished from the stability at large angles to which the metacentric method will not apply.

43. **Isochronous Oscillation.**—When the period of oscillations of a body is always the same, no matter whether the oscillation is large or small.

44. **Lateral Resistance.**—The resistance offered by the immersed part of a ship to making leeway when sailing close hauled or free.

45. **Lateral Resistance, Center of.**—See "Center of Lateral Resistance."

46. **Lever, Righting.**—See "Righting Lever."

47. **Lever, Upsetting.**—See "Upsetting Lever."

48. **Light Displacement.**—By light displacement is understood the vessel with her battery and outfit complete in every particular with the following weights not on board: Officers, crew and their effects, ammunition, stores, including fresh water for drinking purposes and all water in machinery, fuel of every kind, reserve feed water for machinery.

49. **Load Displacement.**—See "Full Load Displacement."

50. **Loll Over.**—A condition of numerically small *negative* metacentric height causing a ship to heel to such an extent that the new position of the center of buoyancy will be in the same vertical line passing through the center of gravity.

51. **Longitudinal Metacenter.**—See "Metacenter, Longitudinal."

52. **Maximum Righting Arm.**—The longest righting arm or righting lever attained by a ship while being continuously inclined.

53. **Mechanical Work.**—The work necessary to heel a ship over to any angle from the upright position. Work is said to be done when a resistance is overcome through space, and is usually expressed in foot-tons when dealing with large amounts.

54. METACENTER, LONGITUDINAL.—The metacenter corresponding to change of trim, or longitudinal inclination.

55. METACENTER, TRANSVERSE.—The metacenter corresponding to heel from the upright.

56. METACENTRIC DIAGRAM.—A diagram showing the vertical positions of the metacenter and center of buoyancy for successive mean drafts of water between the deep load line at which the ship floats when fully loaded, and the light line at which she floats when empty.

57. METACENTRIC HEIGHT.—The metacentric height (*GM*) of a ship is the distance between the ship's center of gravity (*CG*) and the metacenter (*M*), the latter being the point of intersection of a vertical drawn through the ship's center of buoyancy (when inclined through a small angle), with the ship's longitudinal vertical middle plane. This definition of the metacenter (*M*) applies to small angles of 10 to 15 degrees only, or as long, as during the act of heeling, the wedges of emersion and immersion are equal without any change in draft, or as long as the waterlines for the upright and inclined position intersect at the middle line.

58. METACENTRIC HEIGHT, NEGATIVE.—See "Negative Metacentric Height."

59. METACENTRIC STABILITY.—Same as "Initial Stability."

60. METRIC TON.—The French metric ton is 1000 kilograms or 2204.6 pounds.

61. MOMENT OF INERTIA.—If the mass of every particle of a material system be multiplied by the square of its distance from a straight line, the sum of the products so formed is called the "Moment of Inertia" of the system about the line.

62. MOMENT OF INERTIA OF A WATERPLANE, FORMULÆ FOR.—Moments of inertia $= \frac{2}{3}\int y^3 dx$, in which y represents the variable equidistant ordinates of the waterline and dx the uniform distance between these ordinates. It may also be written:

Moment of inertia $= K \times B^3 \times L$ in which B represents the greatest breadth, L the length on the waterline and K a coefficient, the value of which depends on the coefficient of fineness of the waterline.

63. NEGATIVE METACENTRIC HEIGHT.—A condition when the metacenter falls below the center of gravity, and the ship is in unstable equilibrium.

64. NET REGISTER TONNAGE.—See "Tonnage, Net Register."

65. NEUTRAL AXIS OF A SHIP.—The axis passing through the center of gravity of all the material composing the weakest section amidships. By taking moments about the waterline or underside of keel, the vertical height of the center of gravity of the material composing the midship section is soon found. The operation consists simply of multiplying the effective area of each plate, angle iron, etc. (disposed longitudinally and contributing to the longitudinal strength of the ship), by the distance of its center of gravity from the axis about which moments

are taken. If moments are taken about the underside of the keel, all the products will be arithmetically added and divided by the sum of the areas; but if taken about the waterline, the algebraical sum, or the difference of the sums of the products above and below the waterline, will be divided by the sum of the areas. The direction in which the center of gravity is set off from the waterline will be determined by the sign of the algebraical sum.

66. NEUTRAL EQUILIBRIUM.—See "Equilibrium, Neutral."

67. NORMAL DISPLACEMENT.—Normal displacement is the ship completely equipped as in full load, with the exception that instead of the full allowance of stores, coal, fuel, oil and water on board, two-thirds of the amount of these items are considered as making the normal load, or trial displacement. This corresponds to the load line in the design of the ship, and is the one to which the characteristics of length, breadth, draft, etc., are referred.

68. OSCILLATION, ARC OF.—See "Arc of Oscillation."

69. OSCILLATION, PERIOD OF.—See "Period of Oscillation."

70. PERIOD OF OSCILLATION.—The time occupied by a ship in performing one complete oscillation.

71. PITCHING.—A ship's oscillations in a fore and aft direction.

72. PLANE OF FLOTATION.—The plane formed by the surface of the water with the side of the ship.

The same as "Waterline."

73. PLIABILITY.—Pliability is the inverse of stiffness, and is measured by the quantity of strain produced by a certain fixed stress.

74. PROOF STRENGTH.—Proof strength is the utmost stress which a body can bear without suffering a diminution of its stiffness and strength. A stress exceeding the proof strength of the material, although it may not produce instant fracture, produces fracture eventually by long continued application and frequent repetition.

75. RADIUS OF GYRATION.—If M be the mass of a system, and K be such as quantity that MK^2 is the moment of inertia about a given straight line, then K is called the "Radius of Gyration" of the system about that line.

76. RANGE OF STABILITY.—The angle through which a ship must be inclined to reach the point at which the stability vanishes.

77. RESERVE BUOYANCY.—The floating power of that part of the ship contained between the load waterline and the upper deck.

78. RIGHTING COUPLE.—The product of the displacement and length of the righting lever. The displacement being generally expressed in tons, and the lever in feet, the righting couple is given in foot-tons.

79. RIGHTING LEVER.—When a ship is floating upright the Center of Gravity and the Center of Buoyancy are in the same vertical line. In all cases, except when the Metacenter and Center of Gravity coincide,

an inclination of the ship causes the vertical passing through the two points to separate, and the horizontal distance between these verticals is called the righting lever as long as the Metacenter is located above the Center of Gravity, or as long as the movement of the vertical through the Center of Buoyancy, from that through the Center of Gravity, is towards the inclined side.

80. ROLLING.—A ship's oscillations in a transverse direction.

81. SAFETY, FACTORS OF.—See "Factors of Safety."

82. SCENDING.—Same as "Pitching."

83. SECTIONAL AREAS, CURVE OF.—See "Curve of Sectional Area."

84. SET.—Set is the permanent strain or alteration of shape which remains in an imperfectly elastic body after a stress has been removed.

85. SKEW INCLINATION.—A simultaneous transverse and longitudinal inclination.

86. STABLE EQUILIBRIUM.—See "Equilibrium, Stable."

87. STABILITY.—A ship's stability is that quality by virtue of which she tends to right herself when inclined from her position of rest.

88. STABILITY, DYNAMICAL.—See "Dynamical Stability."

89. STABILITY, INITIAL.—See "Initial Stability."

90. STABILITY, METACENTRIC.—Same as "Initial Stability."

91. STABILITY, STATICAL.—See "Statical Stability."

92. STATICAL STABILITY.—The statical stability of a ship may be defined as the effort which she makes when held steadily by a couple in an inclined position to return towards her natural upright position of equilibrium.

93. STEADINESS.—Steadiness in a ship denotes the quality of experiencing little natural tendency to depart from the upright position when subjected to the action of the waves in a sea-way. It is a consequence of moderate metacentric height, therefore crank ships are generally the steadiest.

94. STIFFNESS (as applied to the sea-going qualities of a ship).—Stiffness in a ship is due to a relatively great initial stability, or what is the same thing, when the metacentric height is very large, so that the ship opposes great resistance to the inclination from the upright. A stiff ship follows the motion of the waves with a tendency of keeping vertical to the wave slope.

95. STIFFNESS (as applied to material in construction).—Stiffness is measured by the intensity of the stress required to produce a certain fixed quantity of strain.

96. STRAIN.—Strain is the measure of the alteration of form which a solid body undergoes when under the influence of a given stress.

97. STRESS.—Stress means the intensity of the force which tends to alter the form of a solid body; it is also the equal and opposite resistance offered by the body to the change of form.

98. STRESS, CLASSES OF.—See "Classes of Stress."

99. TON, METRIC.—See "Metric Ton."

100. TONNAGE, DISPLACEMENT.—See "Displacement Tonnage."

101. TONNAGE, GROSS REGISTER.—The total internal capacity of a ship, expressed in hundreds of cubic feet, a register ton being 100 cubic feet.

102. TONNAGE, NET REGISTER.—What is left after deducting from the gross register tonnage certain allowances for the engine and boiler spaces, coal bunkers, crew spaces, etc., is the net register tonnage.

103. TONS PER INCH.—The number of tons of weight required to be placed on board to increase, or required to be removed to decrease, the draft of a ship one inch, for any desired draft of water.

104. TONS PER INCH, CURVE OF.—A curve, from which by measurement the tons per inch can be ascertained for any desired draft of water.

105. TOTAL FLOATING POWER.—See "Floating Power, Total."

106. TRANSVERSE METACENTER.—See "Metacenter, Transverse."

107. TRIM, CHANGE OF.—See "Change of Trim."

108. ULTIMATE STRAIN.—Ultimate strain is the utmost strain or alteration of shape which a body can bear without breaking.

109. ULTIMATE STRENGTH.—Ultimate strength is the stress required to produce fracture in some specified way.

110. UNSTABLE EQUILIBRIUM.—See "Equilibrium, Unstable."

111. UPSETTING COUPLE.—The product of the displacement and length of the upsetting lever. The displacement being generally expressed in tons, and the lever in feet, the upsetting couple is given in foot-tons.

112. UPSETTING LEVER.—When in a ship the Metacenter is located below the Center of Gravity, and the ship is disturbed from the upright position, the vertical passing through the Center of Gravity separates from that through the Center of Buoyancy in the direction of the inclination, tending to upset the ship, hence the distance between the two verticals becomes an upsetting lever.

113. USEFUL DISPLACEMENT.—A term used exclusively by naval architects as applied to warships. It represents the total carrying power of the hull for offence, defence, motive power, endurance and personnel, and includes the weight of armor and machinery, ordnance and ammunition, coal, provisions, water and stores, rigging and equipment, boats, officers, crew and effects.

114. VANISHING POINT.—The angle at which a ship, on being continuously inclined, becomes unstable.

115. VOID SPACE.—Any space in the ship not occupied and to which water can find access in case of leak or accident.

116. WEDGES OF EMERSION AND IMMERSION.—When a ship, floating upright and at rest, is inclined by some external force, the inclination takes place about an axis in or near the longitudinal middle of the waterline, and as the displacement remains constant, the triangular shaped part forced into the water on the inclined side, which is called

the wedge of "Immersion," must be balanced by a similar triangular shaped wedge on the opposite side, which is lifted out of the water, and which is called the wedge of "Emersion."

117. WEIGHT DISPLACEMENT.—See "Displacement, Weight."

118. WEIGHT OF HULL.—The weight of hull of a ship is what is left after removing—besides all consumables—the engines and boilers, masts and riggings, cables, tanks and all the portable equipment; and consists therefore of the weight of the structure proper and its fixed fittings. In armored ships, the armor and backing are also deducted.

119. WINGING WEIGHTS.—Moving weights (already on board) from the middle line towards the sides; it increases the moment of inertia and tends to lengthen the period of the ship.

120. WORKING STRENGTH.—Working strength is the utmost stress to which it is considered safe to subject a body during its ordinary use as part of a structure.

INDEX

A — PAGE

Aaron Manby 1
Acceptance of material 191
After body 7
After perpendicular 9
Air, composition of 354
Air, cubic feet allowed 354
Air, heated system 356
Air, rates of changes of 355
Alabama 313
Annealing 190
Anti-rolling tanks 116
Appendix A 375
Appendix B 398
Approximations in design 16
Arc of oscillation 101
Area of wetted surface 39
Armament, development in 3
Armor 299
Armor, backing 330
Armor bolts 330
Armored cruisers, comparison with battleships 228
Armored cruiser—definition of 168
Armor, framing behind 223
Armor gratings 323
Armor hatches 323
Armor, manufacture of 300
Armor, types of 300
Atwood's formula 73
Auxiliary machinery 334
Axis of rotation 103

B

Backing, armor 330
Balanced hatch 324
Balanced rudder 94, 289
Balancing system 339
Barnes method 75

PAGE
Base line 9
Battle cruiser, definition of 168
Battleships, definition of 168
Battleships, types of U. S. 304
Battleships, stability in battle 86
Beam, effect on stability 83
Beam knees 245
Beams, location of 243
Beams 242
Beams, spacing 243
Beams, sections used for 245
Beams, strong 246
Bending slab 172, 175
Bending test pieces 189
Berth deck 240
Bevel board 174
Beveling 174
Bevel standing 178
Bilge keels 112
Bilge keels, number and arrangement of 113
Bilge keels, effect of emersion of 114
Bilge keels, size of 114
Bilge keels, steadying influence of 143
Bilging, inflow of water, caused by 39
Bilging, sinkage, caused by 38
Block coefficient 13
Board, general 15
Boat cranes 334
Body plan 6
Bolts, armor 330
Bolts, deck 251
Bolts, types of 209
Booklet of general information 271
Bosom piece 210
Bottom, inner 214
Bottom plating 254
Bow and buttock lines 8
Bracket frame 220
Breadth, extreme 10
Breadth, moulded 10
Bridge, aft 239
Bridge deck 239
Bridge, forward 239

PAGE
Bridge, lower 239
Bridge, upper 239
Bronzes 204
Bulkhead liner 258
Bulkheads, center-line 280
Bulkheads, coal bunker 281
Bulkheads, collision 278
Bulkheads, construction of 278
Bulkheads, longitudinal 280
Bulkhead stiffeners 279
Bulkheads, transverse, location of 275
Bunker trolleys 347
Buoyancy, center of 13
Buoyancy, reserve of 82
Butt 254
Button point 208
Butt strap 210
Butts, shift of 254

C

Calculation of center of buoyancy 33
Calculation of weights and centers of gravity........ 18
Calculations 22
Calculations of displacement 27
Calculations, standard ship 77
Calking 210
Camber 11, 242
Carlings 246
Castings, steel 201
Castings, steel, class of 201
Cement 373
Center of gravity and moment of area........ 29
Center line bulkheads 280
Center of buoyancy 13
Center of buoyancy, calculation of........ 33
Center of buoyancy, locus of 35
Center of flotation 48, 13
Center of gravity 13
Center of gravity of solid bounded by curved surfaces and planes... 32
Center of lateral resistance........ 96
Change of trim 60
Chemical analysis 187
Chief characteristics, circular defining 21

PAGE
Circular defining chief characteristics 21
Classification of ships 168
Cleaning castings 202
Cleaning metal surfaces 365
Coal bunker bulkheads 281
Coal bunker ventilation 359
Coaling 341
Coefficient, block 13
Coefficient of fineness of midship section........ 14
Coefficient of fineness of water plane........ 14
Coefficient, prismatic 14
Cofferdams 90, 324
Collision bulkheads 278
Compartments, rules for numbering 267
Compartments, watertight 282
Compensating system 339
Composite construction 368
Conditions of equilibrium 45
Connecticut 316
Corrosion 364
Corrosion, prevention of inside 371
Cost of ships 5
Cranes, boat 334
Cross curves of stability 77
Cruiser, plating of 264
Cruisers, protection of 324
Curve of displacement 27
Curve of flotation 103
Curve of tons per inch immersion 28
Curves, cross, of stability 77
Curves of areas, midship section 29
Curves of extinction 110

D

Dead flat 7
Deck, berth 240
Deck, bridge 239
Deck, gun 240
Deck, half 242
Deck lines 8
Deck lines at side 8
Deck, lower 240
Deck, main 241

PAGE
Deck, orlop 240
Deck planking, method of laying 251
Deck, platform 242
Deck plating 246
Deck, poop 239
Deck protection 299
Deck, protective 240
Deck, quarter 239
Deck, second 241
Deck, upper 239
Deck, watertight 240
Deck winches 334
Decks 239
Deck, forecastle 239
Decks, nomenclature of 239
Decks, protective, construction of 249
Decks, splinter 240
Decks, strength 247
Decks, watertightness of 250
Decks, wood 251
Definition of Naval Architecture terms 398
Definition of ship building terms 375
Delaware 318
Denver class, framing of 233
Depth, moulded 10
Design, actual 17
Design, approximation in 16
Design, plans and data 18
Designer's water line 11
Destroyer, framing of 237
Destroyer, plating of 264
Detail specifications 18
Detailed weight calculation 21
Determination of rolling period 106
Development in armament 3
Development in propulsion 2
Diagonal lines 9
Diameter, tactical 98
Difference in draft between sea water and river water 37
Dimensions of wave, formula for 130
Displacement 12
Displacement calculations 27
Displacement curve 27

PAGE

Displacement in fresh water 28
Displacement scale 36
Displacement, when floating out of the designed trim............. 62
Division of material 15
Docking 181
Docks 181
Docks, graving 184
Docks, floating 184
Docks, list of 182
Dogs, bending slab 177
Doubling plates 259
Draft 11
Draft, aft 11
Draft, difference in, between sea water and river water............ 37
Draft, extreme 11
Draft, forward 11
Draft marks, location of 11
Drag 11
Drainage system 337
Drainage system, main 337
Drainage system, secondary 338
Drift angle 97
Dubuque class, framing cf.. 236
Dynamical stabilty 92

E

Eddy resistance 165
Effect of adding weights 64
Effect of shifting weights on stability 88
Effect on trim of adding weight of considerable amount............ 65
Elastic limit 187
Emerged wedge 50
Equilibrium, conditions of 45
Equilibrium, neutral 45
Equilibrium, stable 45
Examination of hulls 372
Exhaust system of ventilation 352
Ex-*Pennsylvania*, U. S. S.. 327
Experiments, inclining 53
Experiments, model tanks, plotting of 165
Experiments, rolling 108
Extinction, curves of 110
Extreme breadth 10

F

PAGE
Fairing the body 171
Faying surface 178
Fire main 339
Flat keel 256
Flats, plating of 250
Flooding 339
Floor plates, lighted 220
Florida 319
Flotation, center of 13, 48
Flotation, curve of 103
Fluid pressure, variation of direction and intensity of, in wave.... 127
Fluid resistance, character of 107
Flush point 208
Forebody 7
Forecastle decks 23
Forward perpendicular 9
Fouling 364, 367
Frahm tanks 116
Frames, bracket 220
Frames, watertight 220
Framing 214
Framing at ends of ships 226
Framing, behind armor 223
Framing, longitudinal 215
Framing of *Denver* class 233
Framing of destroyer 237
Framing of *Dubuque* class 236
Framing of protected cruiser 229
Framing of scout vessels 233
Freeboard, effect on stability 82
Free water, effect of 57
Free water in the hold, influence of 121
Fresh water system 340
Froude's law 155

G

General board 15
General information, booklet of 271
General instructions for painting 365
General specifications 18
G. M., values of 56

PAGE
Gratings, armor 323
Gravity, center of 13
Ground ways 180
Gun-boat 169
Gun deck 240
Gyroscope, Schlick 120
Gyroscope, Sperry 120

H

Half breadth plan 6
Half deck 242
Hammer tests for rivets 200
Hatch, balanced 324
Hatches 253
Hatches, armor 323
Heaving oscillation 145
Heeling, due to putting over rudder 96
Height of wave 122
High tensile steel rivets 200
Hogging 150
Hull material, working of 204
Hulls, examination of 372

I

Immersed wedge 50
Immersion, curves of tons per inch 28
Inclinations, transverse 50
Inclining experiment 53
Inflow of water by bilging 39
Influence of free water in the hold 121
Influence on range of stability 81
Inner bottom 214
Inner bottom, plating of 260
Inner strakes 179
Inspection of materials, general specifications for 186
Inspection of materials, manner of conducting 186
Inspection stamps 191
Instruments for calculations 22
Intercostal members 151
Internal structure of wave 125
Iowa 311
Isochronous oscillation 105

K

PAGE
Kearsarge 312
Keel block 178
Keel, flat 256
Keels 214
Keels, bilge 112
Keels, bilge, effect of emersion of........ 114
Keels, bilge, number and arrangement of........ 113
Keels, bilge, size of........ 114
Keels, bilge, steadying influence of........ 143
Knees, beam 245

L

Laps, types of........ 211
Lateral resistance, center of........ 96
Launching 180
Law of comparison 155
Laying off 171
Length between perpendiculars........ 9
Length of wave 122
Length overall 10
Lengths of wave, observations of........ 131
Light draft 11
Lightened floor plates 212
Liner, bulkhead 258
Load draft 11
Local strains 152
Location of draft marks........ 11
Location of transverse bulkheads........ 275
Locus of center of buoyancy........ 35
Longitudinal bulkheads 280
Longitudinal framing 215
Longitudinal metacenter 59
Longitudinals, spacing of........ 256
Lower deck 240

M

Machinery, auxiliary 334
Magazine refrigeration 362
Magazine refrigeration system........ 357
Main deck 241
Main drainage system........ 337
Maine 314
Manby, Aaron 1

PAGE
Margin plating 264
Marine railway 184
Material, division of.... 15
Material, miscellaneous 205
Material, rejection of 191
Materials for building ships.... 186
Materials, general specifications for inspection of.... 186
Mean draft 11
Metacenter 13
Metacenter, longitudinal 59
Metacenter, transverse, location of 45
Metacentric height 52
Metacentric diagram 52
Metacentric height, values of.... 56
Metacentric method of stability.... 52
Metal surfaces, cleaning.... 365
Middle body 7
Mid perpendicular 9
Midship section 7
Midship section, curves of area.... 29
Mixture of paints 365
Model plating 170
Model tank 154
Model tanks, list of.... 156
Models, material for 160
Models, preparation of 163
Models, rolling experiments with.... 111
Mold loft 169
Moment and center gravity of area.... 29
Moment of statical stability.... 52
Moon bar 177
Mosley's formula for dynamical stability.... 92
Motion of ship compared with pendulum.... 102
Moulded breadth 10
Moulded depth 10

N

Naval Architect terms, definition of.... 398
Neutral equilibrium.... 45
Nevada 322
New system for numbering compartments.... 269
New York 321
Nomenclature of decks.... 239
North Carolina, U. S. S 329

O

PAGE
Observations during rolling experiments 109
Observations of heights of waves 133
Observations of rolling and pitching 147
Orbital motion of particles in wave 123
Oregon 310
Orlop deck 240
Oscillation, arc of 101
Oscillation, isochronous 105
Oscillation of ships 101
Oscillations, heaving 145
Oscillations in a sea wave, character of 135
Outside plating 254
Overall length 10

P

Painting 364
Painting, general instructions for 365
Paints, mixture of 365
Panting 152
Parallel middle body 7
Path of ship in turning 98
Pendulum, motion of ship compared with 102
Percussive tests on castings 203
Period 101
Period, changes in by changes in distribution of weights 106
Period, determination of rolling 106
Period of wave 122
Periods of various classes of war vessels 111
Perpendicular, aft 9
Perpendicular, forward 9
Perpendicular, mid 9
Physical tests of materials 187
Pickling 204
Pitching 101
Pitching and 'scending 144
Pittsburg, U. S. S. 327
Pivoting point 97
Planning a ship 15
Plans of a ship, for building 169
Plates, steel 192
Plates, universal 195
Platform deck 242

PAGE
Plating, behind armor 259
Plating, deck 246
Plating of a battleship 255
Plating of a cruiser 264
Plating of destroyer 264
Plating of *Dubuque* class 264
Plating of inner bottom 260
Plating of a scout 261
Plating model 170
Plating, outside 254
Plenum system of ventilation 352
Plotting, results of model tank experiments 165
Plumbing system 340
Poop deck 239
Pressure, fluid, variation of direction and intensity of 127
Prevention of corrosion inside 371
Prismatic coefficient 14
Problems 39, 70
Propulsion, development in 2
Protected cruiser, framing of 229
Protection of cruisers 324
Protective deck 240
Protective decks, construction of 249

Q

Quarter deck 239

R

Raft body 89
Railway, marine 184
Range of stability 77
Range of stability, influences on 81
Refrigeration, magazine 362
Refrigeration system, magazine 357
Rejection of material 191
Reserve of buoyancy 82
Resistance 154
Resistance, eddy 165
Resistance, estimation of 107
Resistance, fluid, character of 107
Resistance, skin 165
Resistance, wave 165
Ribbands 179

PAGE
Righting arm 75
Rise of floor 11
Rivet rods 198
Riveting in outside plating........ 256
Rivets, countersunk head 207
Rivets, hammer tests on 200
Rivets, pan head 207
Rivets, points, types of 208
Rivets, steel 198
Rivets, tap 207
Rolling 101
Rolling, agents producing 104
Rolling among waves, effect of fluid resistance on........ 142
Rolling amongst waves of synchronizing periods........ 139
Rolling and pitching, observations of 147
Rolling, effect of waves in producing........ 136
Rolling experiments 108
Rolling experiments, observations during 109
Rolling, experiments with models 111
Rolling periods of various classes of war vessels........ 111
Rolling, practical investigations on unresisted........ 141
Rolling, unresisted, assumption for mathematical investigation of.. 138
Rotation, axis of 103
Round up 11
Rudder, balanced 289
Rudder, heeling, due to putting over 96
Rudder stock 293
Rudder, types of 94, 289
5-8 rule 25
Rules for numbering compartments........ 267
Rules for numbering compartments, new system........ 269
Rust 364

S

Sagging 150
Salt water system 340
San Marcos, U. S. S........ 309
Scale, displacement 36
Scantling 152
Scantling, various members........ 218
'Scending 101
'Scending and pitching 144
Schlick gyroscope 120

PAGE
Scout, plating of 261
Scout vessels, framing of 233
Scrive board 171
Scupper system 338
Seam strap 210
Second deck 241
Secondary drainage system 338
Section, midship 7
Shaft struts 298
Shapes, ship building, types of 206
Shaped, steel 196
Sheathed ships 2
Sheer 9
Sheer line 9
Sheer plan 6
Shift of butts 254
Ship building terms, definitions of 375
Ship calculations, standard 77
Simpson's first rule 22
Simpson's second rule 23
Sinkage, caused by bilging 38
Sketch plans 16
Skin resistance 165
Sliding ways 181
Slope of wave, maximum 129
Smashed point 208
Snap point 208
Solid bounded by curved surfaces and planes, center of gravity of... 32
Solid bounded by curved surfaces, volume of 26
South Carolina 317
Spacing of longitudinals 256
Specifications, detail 18
Specifications, general 18
Speed of wave, formula for 130
Sperry gyroscope 120
Splinter deck 240
Stability at large angles 73
Stability, dynamical 92
Stability in battle 86
Stability, range of 77
Stability, statical 45
Stability, statical moment of 52
Stable equilibrium 45

PAGE

Stanchions ... 246
Standard ship calculations ... 77
Standard classification of weights ... 20
Statical stability ... 45
Statical stability, moment of ... 52
Steadying apparatus, Thornycroft ... 119
Steel castings ... 201
Steel plates ... 192
Steel rivets ... 198
Steel shapes ... 196
Steering and turning ... 94
Stems ... 287
Sternposts ... 288
Stiffness ... 56
Strains, local ... 149, 152
Strains, structural ... 149
Strakes ... 179
Strap, butt ... 210
Strap, seam ... 210
Straps, types of ... 211
Strength ... 149
Strength, decks ... 247
Strength, experiments on ... 151
Stresses, transverse ... 152
Strong beams ... 246
Struts, shaft ... 298
Subdivision ... 275
Submarine ... 169

T

Tactical diameter ... 98
Tactical diameters, values of ... 100
Tanks, Frahm or anti-rolling ... 116
Tenderness ... 86
Test pieces ... 187
Test pieces, bending ... 189
Test pieces, flaws in ... 189
Test pieces, location of ... 189
Test pieces, section of ... 189
Test pieces, types of ... 188
Test pieces, treatment of ... 190
Testing machines, care of ... 187
Testing machines, pulling speed ... 187

PAGE
Testing water 282
Tests of materials 186
Tests, material exempt from 190
Tests, percussive, on castings 203
Texas 309
Thornycroft steadying apparatus 119
Tolerances in rivets 199
Tolerances permissible, variations in, for plates 195
Torpedo boat destroyer 169
Torpedo boat destroyer, framing of 237
Transverse bulkheads, location of 275
Transverse inclinations 50
Transverse metacenter 45
Transverse stresses 152
Trapezoidal rule 25
Trim, effect of adding weight of considerable amount 65
Trim 11
Trim, caused by compartment open to the sea 68
Trim, change of 60
Trim, effect on, of adding weight 61
Trim, effect of change of on speed 115
Trim, effect on displacement 63
Trochoidal theory 122
Trolleys, bunker 347
Turning trials 100
Types of bolts 209
Types of rivet points 208
Types of test pieces 188
Types of U. S. battleships 304

U

Universal plates 195
Unstable equilibrium 45
Upper deck 239
U. S. battleships, types of 304

V

Valves, ventilation 286
Ventilation 350
Ventilation, cleaning system 352
Ventilation, coal bunker 359
Ventilation, exhaust system 352
Ventilation, heated system 356

PAGE
Ventilation systems of various decks.... 358
Ventilation, valves 286
Virginia 315
Volume of solid bounded by curved surface.... 26

W

Washington, U. S. S.... 328
Water chambers 115
Water, free, effect of.... 57
Water, free in hold, influence of.... 121
Water lines 8
Water testing 282
Watertight compartments 282
Watertight deck 240
Watertight frames 220
Watertightness of decks.... 250
Wave, formula for dimensions and speed of.... 130
Wave, height of 122
Wave, internal structure of.... 125
Wave, length of.... 122
Wave, maximum slope of.... 129
Wave, period of.... 122
Wave resistance 165
Waves, effect of in producing rolling.... 136
Waves, observations of heights of.... 133
Waves, observations of lengths of.... 131
Weight, calculation detail.... 21
Weights and centers of gravity, calculation of.... 18
Weights, effect of adding.... 64
Weights, effect of shifting on stability.... 88
Weights of materials.... 191
Weights, standard classification of.... 20
Welding castings, when permitted.... 204
Wetted surface, area of.... 39
Winches, deck 334
Wolverine 1
Wood bolts 251
Wood decks 251
Working hull material.... 204
Wyoming 320